facies Dbs of the Vermilion area. Load structures at the base of the sediment, small water expulsion features and stringers of coarse particles at the base of diamicton bands such as those observed in facies Dbs are common. Basal contact of the sand lenses with the diamictons is usually sharp and conformable and non-erosional such as described in sediment gravity flows (Lawson 1979). This facies is thus interpreted as subaerial gravity flow deposits.

5.2.5 Dsi: INTERBEDDED DIAMICTON, SAND AND SILT

This facies consist of massive diamicton beds interbedded with continuous silty clay, silt and sand laminae (Plate 13).

The diamicton beds are unstructured and vary in thickness from 5 to 19 centimetres. They have a lower percentage of coarse fragments than the other diamicton facies observed in the map area. Subrounded mud clasts, composed of silty clay or clayey diamicton were observed within the diamicton bands in three exposures. No sheared clasts or striations were observed

The sandy and clayey silt laminae are usually less than 3 centimetres thick, are continuous, show normal grading, and are often rhythmically bedded. Contacts are well defined, erosional, and may be draped or loaded by coarse fragments in the diamicton beds. The sandy beds are usually associated with diamicton beds, are massive and usually less than 2 centimetres thick. The relative proportion and thickness of the diamicton, sand and silty beds vary greatly from one exposure to another. However, they are always so closely associated and interbedded with each other that it is not practical to divided them into subfacies.

Thickness of this facies varies between 0.5 to 1.3 metres and lateral thickness from 4 metres to 9 metres.

Example: This facies is found in sections CM86-2, CM6-19 (see Appendix 4).

INTERPRETATION

The presence of well sorted and continuous laminated silt, silty sand and silty clay, of silt and clay pellets, the draped clasts, and the stratified appearance of the deposits support a subaqueous deposition mechanism for this facies. The massive diamicton beds containing soft clasts and showing well defined contacts with the stratified beds are probably the result of subaquous sediment flow (Evenson et al, 1977; Kurtz and Anderson, 1979).

The silty clay and silty beds are often rhythmically bedded and with tabular bedding which suggests deposition in a lacustrine environment. The silty sand and sandy laminae are probably the result of winnowing of the surface of the massive diamicton by lake bottom currents (Kurtz and Anderson, 1979; Domack, 1982) or deposited by turbidity currents (Middleton and Hampton, 1976) or simply by the settling of particles through quiet water. Large clasts falling or dropped into such material would deform underlying beds (Kulig, 1986).

The convolutions or deformations can be attributed to settling of deposits after melting of underlying ice or slumping of ice walls.

This facies was probably deposited in small shallow lakes of glacial origin where saturated till would either flow from the margin or from ice walls or grounded ice at intermittent periods depositing the diamicton beds and sandy beds. The remainder of the time, normal glaciolacustrine processes would deposit the silty clay and silty sand laminae.

5.2.6 Dk: MASSIVE DIAMICTON WITH INCORPORATED BLOCKS OF SEDIMENT

This facies is composed of massive diamicton containing angular and subangular blocks of bedrock (shale, siltstone, ironstone or sandstone), sand and gravel or diamicton of a different color (Plate14).

The incorporated blocks of material range in size from 0.3 x 0.5 metres to 5 x 7 metres. When the incorporated sediments are stratified, faulting and folding is commonly visible. Massive bedrock blocks (e.g. shale) result in a highly disturbed facies with blocky subangular fragments, which often have iron-stained, polished or slickensided surfaces. Lithified bedrock blocks such as ironstone or sandstone beds, are usually crumbly and broken. Contacts between the diamicton and the incorporated blocks can be sharp or mixed (melange).

Lower contacts with other facies were not observed and lateral contact are usually poorly defined. Thickness varies between 2 metres to 10 metres and lateral thickness from 5 metres to 50 metres.

Example: This facies is found in sections CM82-70, CM83-74, CM86-11 (see Appendix 4).

INTERPRETATION

This facies is interpreted as the result of melting of supraglacial till. The origin of the massive diamicton was discussed earlier. The inclusions were detached from the interface bedrock or previous sediment and ice, incorporated as blocks either at the sole or at the front of advancing ice. As ice becomes static and melts, they are let down with the diamicton. Andriashek and Fenton (1989) describe similar inclusions as component of rubble moraine and suggest that the sizes of the inclusions becomes smaller down ice from the source as the glacier crushes and breaks them. These incorporated blocks may or may not have been frozen when they were picked up by the glacier and it is possible that frozen blocks would survive longer and preserve most of their original shape and show little deformation or faulting.

Bf: DISTURBED (FOLDED OR FAULTED) BEDROCK

When folds and faults are present in the originally flat lying bedrock strata, or presence of underlying glacial sediment is identified, then the bedrock is considered disturbed (Plate 8).

Example: This facies is found in sections CM84-6, CM84-9, CM86-5 (see

Appendix 4)

INTERPRETATION

Bf is interpreted as the result of glaciotectonic processes and is therefore included in this discussion of glacial facies. Deformation, separation and displacement of bedrock or older material as described in Bf have been observed in the Prairies (Kupsch, 1960; Moran 1980; Moran et al., 1980; Bluemle and Clayton, 1984; Aber, 1984 ; Andriashek and Fenton, 1989) as well as in Europe (Banham, 1977; Berthelsen, 1979; Aber, 1982; Ruszczynska-Szenajch, 1987) as well as deformation from simple to multiple thrust folding at or near margin of advancing or readvancing ice.

5.5 OTHER DEPOSITS

Numerous studies of glaciofluvial and glaciolacustrine deposits provide detailed description and discussions of their sedimentary features and possible depositional environments and it is not necessary or neither is it part of the objectives of this thesis to discuss them. They are therefore described in the sections in term of grain size range, sorting, stratification and thickness (Table 9). Glaciolacustrine sediments are indicated by the code GL and glaciofluvial deposits by the code GF.

GF-GLACIOFLUVIAL DEPOSITS

Deposits composed of sands and gravels with occasional silt cappings were observed as part of the sections studied in the area. All surface and section exposures of such gravels contained granitic clasts originating from the Shield and are therefore considered as post Tertiary. The association with glacial landform and deposits, their geographic location, and crude stratification and sorting were considered sufficient to classify them as glaciofluvial in origin.

GL-GLACIOLACUSTRINE

Laminated and massive well sorted silt, clay and fine sand deposits of restricted surface coverage were mapped as glaciolacustrine in origin and identified by the code GL. Presence of occasional till clasts, soft clasts, draped clasts were occasionally observed and confirmed the glacial origin of silt and clay beds.

B: UNDISTURBED BEDROCK

The local bedrock consists of massive to laminated shales, interfingering beds of siltstone, ironstone and sandstone gently dipping northeastward and is described in detail in Chapter 2. These formations are considered undisturbed if bedding appears flat lying with a very gentle dip and no evidence of underlying Quaternary deposits, faulting or displacement could be detected.

CHAPTER 6 FACIES ASSEMBLAGES AND LANDFORM MODELS

6.1 INTRODUCTION

Since the early studies in glacial geology, glacial landforms have been described with an increasing awareness and knowledge of the complex and multiple sedimentary processes involved. Lithofacies analysis has been used with success to describe sections, and to decipher stratigraphic problems (Proudfoot,1985; Kulig, 1986; Levson and Rutter, 1986; Eyles et al., 1988). In this chapter, a facies scheme is used as a tool to describe the distribution and the internal organization of sediments in selected glacial landforms.

The east half of the Vermilion map sheet contains terrain types common to most of the Canadian Prairies. The fine-grained, poorly lithified nature of Cretaceous bedrock is reflected in the silty clay to silt loam texture of diamictons and low content of pebbles and cobbles. A variety of glacial landforms such as stagnant ice moraine, glacially streamlined landforms and glaciotectonic terrain are preserved here as they are in many other locations in the prairies.

The surface geology map (Figure 3 in back pocket) shows the major morainic units identified within the map area. This chapter relates an assemblage of facies (described in Chapter 5) to selected glacial landforms dominantly composed of diamicton and proposes a landform model for each of these moraine types.

Facies assemblages from terrain types such as irregular stagnant ice moraine (MSI), fluted moraine (MF), rubble moraine (MR) and thrusted moraine (MT) are discussed and a composite model is derived from the observations made in the field.

A type section was selected for each landform as the most representative. Facies variation and frequency are qualitatively discussed in the description of the glacial landform. A generalized and composite facies assemblage is suggested for each selected glacial landform. Appendix 4 contains sketches of sections not described in this chapter.

Comments on the physical properties of each landform model include both description of the expected behavior of the upper metre of each unit, of interest for those concerned with the surface behavior of the terrain, and comments on the engineering properties at the landform scale . This information may assist the planning of site specific investigation and increase the awareness of possible problems. Those observations are summarized on Table 10 and highlighted in the section called "Applied Aspects" for each landform model.

6.2 MSI-IRREGULAR STAGNANT ICE MORAINE

A total of 7 sections in this landform type provided sufficient exposures and are described (see Appendix 4) according to the facies scheme described in Chapter 5.

The dominant facies in this moraine type, as shown in the type-section CM86-8 (Figure 24) is massive diamicton (Dm), with frequent occurrences of banded diamicton and silty sand (Dbs). Other facies may include diamicton with sand lenses (Ds), diamicton with bedrock inclusions (Dk) and rarely, interbedded diamicton and sand (Dsi).

The dominant presence of massive diamicton (Dm) associated with the banded diamicton and silty sand (Dbs) is consistent with an environment in which abundant meltwater causes a reduction of strength of sediments which subsequently move under gravity as a mass flow. The melting ice base provides ample supply of melt water to the glacial debris and creates instability for the saturated material. Structures created during gravity flow may partially be preserved as banded diamicton and silt facies (Dbs) or destroyed during further slumping, which explains the absence of sedimentary structures for most of exposed diamicton in sections.

This environment may also include the deposition of small meltwater deposits

Table 10 Applied aspects of selected landforms.

LANDFORM	Stagnant Ice Moraine	Fluted Moraine	Rubble Moraine	Thrusted Moraine
GENERAL RANGE OF PHYSICAL PROPERTIES				
Permeability	L,MV	L,RV	L-H,VR	L-H,RV
Moisture holding capacity of the first metre	H, RV	H,RV	H-M,MV	H-L,VV
Bearing strengh	M,RV	M,RV	M,MV	M-L,VV
LAND USE RATING (INCLUDING MOST LIMITING FACTORS)				
Liquid waste disposal	S	S	U (I)	U (I)
Solid waste disposal	S	S	FS (I)	U-FS (I)
Construction (highway)	S (T)	S (T)	S (T)	U-FS (T)
HGeavy foundations	FS	FS	FS	FS
Septic tank systems	U (D)	U (D)	U (D)	U-FS
Excavation	S	S	FS (I)	FS-U (I)
Cultivated agriculture	S-FS (T)	S	FS (T)	FS-U (T,I)

ALL THE ABOVE APPLY TO UNJOINTED DEPOSITS. JOINTS WILL INCREASE PERMEABILITY AND MAY INCREASE RISK OF FAILURE DURING EXCAVATION.

High: H	Suitable: S	Poor drainage: D
Medium : M	Fairly suitable: FS	Steep topography:T
Low:L	Unsuitable:U	Presence of bedrock inclusions (or others):I

Very Variable:VV
MV: moderately variable
Rarely Variable:RV

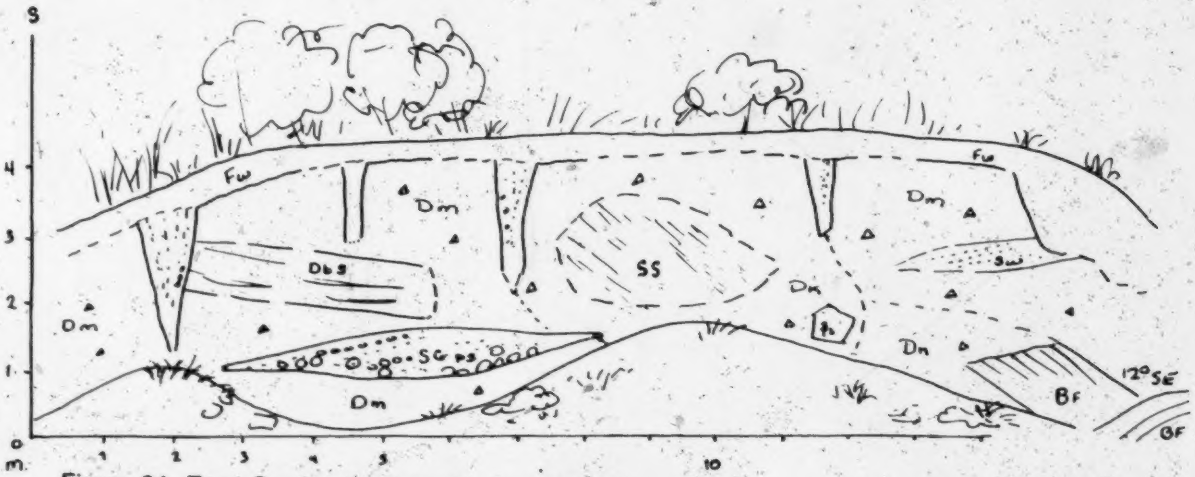

S
4
3
2
1
0
m.
1
2
3
4
5
10
Fw
Dm
Dbs
SGps
SS
Dk
Dn
Sw
Bf
12°SE
BF

Figure 24 Type Section for Stagnant Ice Moraine

CM86-8 **STAGNANT ICE MORAINE**

LOCATION TWP 54, RGE 5 W 4, SEC 1, LSD NE 1

Dm: massive diamicton
Dk: massive diamicton with inclusions
Dbs: banded diamicton and silty sand
Bf : disturbed bedrock
Fw: well sorted silt, massive
SGp: sand and gravel poorly sorted

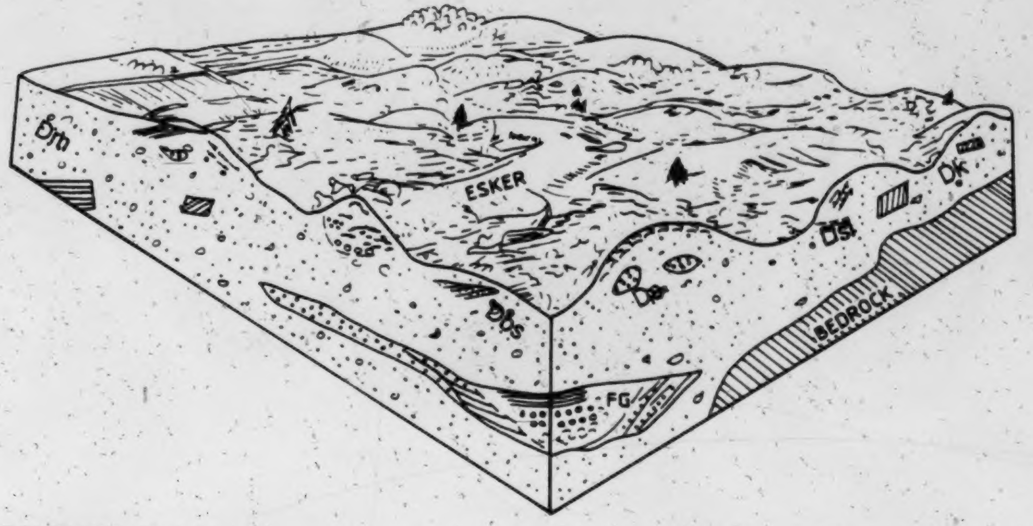
This section is located directly west of the Landonville ridge and shows some ice wedges and a loess blanket.

which may be preserved as sand lenses to form the facies Ds (diamicton with sand lenses). At depth, facies Ds also might represent englacial ice in which sand lenses and massive diamicton were deposited during melt out of the debris rich ice bands. The bedrock inclusions (Dk) were preserved and deposited within the diamicton when the ice melted. The preservation of diamicton associated with the glaciolacustrine environment such as facies Dsi indicates that ice contact lakes formed at the surface of or in contact with the stagnant ice walls. Such deposits are small and infrequent which suggest that the lakes were indeed small, shallow and possibly short lived.

Associated glaciofluvial sand and gravel are common and usually form a small percentage of the exposures, occasionally as a thin veneer or as a unit with lateral contact with the diamicton facies, more specifically in the lower sides of the ridges or in depressions. Modern ponding in the depressions is very common particularly in the high relief terrain. Slope wash deposits are also common particularly in the higher relief moraine

LANDFORM MODEL FOR THE IRREGULAR STAGNANT ICE MORAINE

Based on the previous observations, the landform model for stagnant ice moraine (Figure 25) is composed mainly of massive diamicton (Dm) associated with banded diamicton and silt (Dbs) which usually occurs within three metres from the surface. Diamicton with sand lenses (Ds) occasionally occurs at depth greater than 2 metres and massive diamicton with bedrock inclusions (Dk) can occur at any depth within the landform. The rarely occurring interbedded diamicton, fine sand and silt (Dsi) is usually found close to the surface. Its preservation may depend on the sequence of deposition. In theory, ice contact glaciolacustrine deposits should have been abundant in this depositional environment but might not have been preserved because of the high rate of slumping and resedimentation taking place in such an



DOMINANT FACIES

Dm - Massive diamicton

ASSOCIATED FACIES

Dbs - Banded diamicton and silty sand

Ds - Massive diamicton with sand lenses

Dk - Massive diamicton with bedrock inclusions

RARELY OCCURRING FACIES

Dsi - Interbedded diamicton, sand and silt

Figure 25: Landform Model for Stagnant Ice Moraine (Msi)

unstable and saturated environment. This might also explain the relative abundance of massive diamicton over all other facies types.

APPLIED ASPECT

At the surface, this landform may have lateral variations of clay content mostly due to slope wash processes as slopes are usually quite steep. In this situation permeability is low and is slightly variable reflecting the changes of texture. Drainage is generally quite poor in depressions. Occurrence of other facies, and therefore large variations of texture, permeability and strength, are still possible within the first metre from the surface but are generally of small areal extent. Bedrock and sandy inclusions are rarely connected therefore they would cause little variation of physical properties.

At greater depth, the massive diamicton facies is still dominant but the possibility of intersecting other facies increases. Facies such as Dbs, Ds, and Dk usually occur at depth greater than two metres and thus changes of limited extent in permeability, strength and porosity are possible within the landform. This landform is generally unsuitable for septic tank locations and presents a low risk of spill contamination over vertical or lateral distances unless local bodies of extensive glaciofluvial sand and gravel are intersected at depth The steep topography combined with the poor drainage in depressions are usually the main obstacle both for agricultural and residential development (also see Table 10). Joints are sometimes present at various densities and at depth up to two metres. A well developed joint system will greatly increase the permeability of the landform.

6.3 MF-FLUTED MORAINE

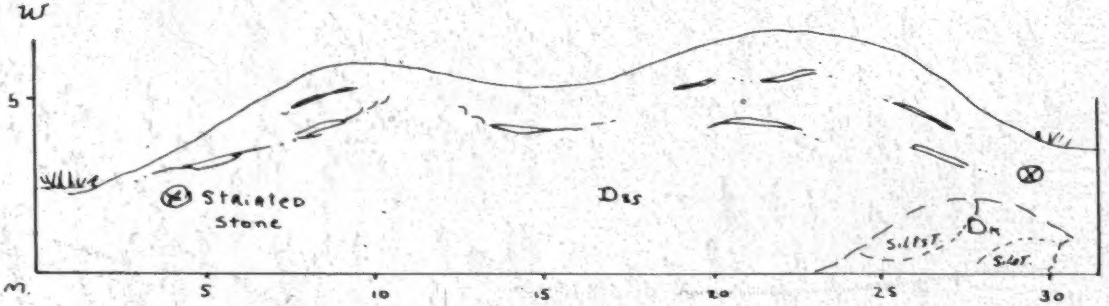
The low relief of this unit limits the number and quality of exposures, therefore, only four sections through fluted moraine were described (see Appendix

4). The dominant facies in all four sections is diamicton with sand stringers (Dss) as seen in type section CM86-13. Diamicton with bedrock inclusions (Dk) is described in one exposure as a minor component.

The type section, CM86-13 (Figure 26) ismostly composed of the facies Dss. Fine-grained sediment deposited by slope wash processes forms a veneer in the inter-ridge depressions.

Most known theories for the origin and development of streamlined features are based on the association of flutes with boulders at their point of initiation (Boulton 1976). No such boulder/ridge relationship was present in the Vermilion area and the fluting field originated many kilometers further north of the map sheet (Shetsen, 1990). Other theories which do not require the presence of boulders at the head of the flutes suggest that a rhythmic mechanism is responsible for their formation. Baranowski (1970) proposes that frost heaving between cold and temperate zones of the glacier base might generate such features.

Jones's(1981) field investigations of the moraines in the Vermilion area and vicinity included fabric measurements and textural analysis. From his observations he concluded that the most applicable theory for the formation of these flutes was a combination of ideas put foward by Moran et al. (1981) and Shaw and Freschauf (1973). At the head of the flute field, frozen bed conditions and compressive flow existed near the margin of the ice, resulting in the plucking of large bedrock blocks. Low pressure zones were created in the lee of these blocks as the ice continued flowing under thawed bed conditions (Moran et al.,1981). Jones then explains the infilling of these cavities by the lateral accretion and transport of debris into them by helicoidal ice flow cells. These flow cells (Shaw and Freschauf, 1973) are developed parallel to the main ice flow with adjacent cells rotating in opposite directions causing pasting and squeezing of the subglacial sediments into the low pressure zones. Origin of the cells has not been explained, but Jones assumes that



W
5
m.
5
10
15
20
25
30
Striated Stone
Dss
Dk
Siltst.
Silt.

Figure 26 Type Section for Fluted Moraine

CM86-13 **FLUTED MORAINE**

LOCATION:TWP 55, RGE 5 W 4, SEC 10, LSD NC 15.

Dss: DIAMICTON WITH SAND STRINGERS

Dk: MASSIVE DIAMICTON WITH INCLUSIONS

thrusted blocks north of the flutes would be sufficient to initiate such flow differentiation. However, the width and height of the landforms (less than 100 metres apart and 1 metre high) suggest a multitude of co-existing flow cells within a short distance and there is no evidence to suggest that the flutes are not contemporaneous.

Recent theories (Sharpe 1987; Shaw, 1983 and 1987; Shaw and Kvill, 1984; Shaw, Kvill and Rains, 1989) explore the importance of subglacial meltwater in the formation of drumlins and flutes as erosional and/or depositional landforms.

Drumlins, and in some cases flutes, may result from the infillings of subglacial cavities or scour marks left on the sole of the ice by subglacial meltwater floods. These drumlins are composed of stratified sand and gravel, have boulder concentrations near the surface of the landforms and show evidence of resedimentation by mass movement (Shaw and Kvill, 1984, Shaw, 1987). In other cases, drumlins may be the remnant ridges of subglacial sediments (in some cases bedrock) eroded and streamlined by subglacial meltwater during flood-like events. These drumlins are commonly associated with other erosional landmarks such as crescentic scour marks, gouging, and striations.

In the Vermilion area, no erosional indicators and no associated glaciofluvial deposits associated with high meltwater flow are found in vicinity of or south of the fluting field of the Irish Creek Plain. There is no evidence that meltwater played a major role in their formation but it is possible that further work and new exposures might increase our understanding of the formation of these particular streamlined ridges.

Boulton (1976) suggests that the term flutes should be restricted to the assemblage of ridges and grooves resulting from post depositional deformation of subglacial sediment by the active ice sole. The flutes in this area appear to result from a pasting process, a combination of shearing and molding, and might best be explained by the theory of Moran et al. (1981).

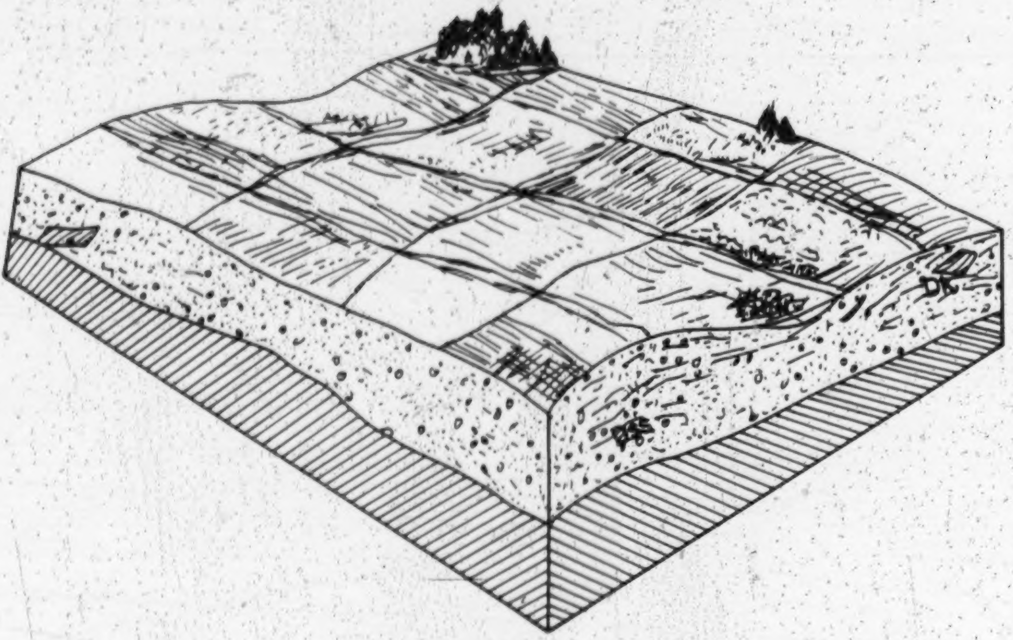
LANDFORM MODEL FOR FLUTED MORAINE

The landform model (Figure 27) is composed mainly of Dss (diamicton with sand stringers) with rare occurrences of Dk (diamicton with bedrock inclusions). The addition of modern sediments consists of fine grained deposits associated with slope wash.

APPLIED ASPECTS

The exposed surface or the first metre of the landform would probably have a slightly higher permeability than the moraines formed mostly of massive diamicton due to its higher sand content. The sand stringers, if not always connected, were commonly linked to joint planes and would therefore increase potential flow paths at a local scale. The surface of this moraine may be less susceptible to cementation of the clay and silt fraction, and to frost heaving because of the high density of small sand bodies. The inter-ridge depressions commonly appear moderately to poorly drained compared to the crest and sides that are moderately well drained. Large clasts or boulders are present at or close to the surface but less frequently than on other moraine types described.

Within the landform itself, properties and behavior of the diamicton are fairly predictable and consistent. Internal composition of the landform is quite homogeneous and the probability of bedrock inclusions is low, thus physical properties such as bearing capacity, shearing strength and permeability are relatively uniform within the landform (also see Table 10). The presence of numerous thin sand stringers might increase permeability laterally over distances on the order of 5 to 6 metres. However, in a general sense, this moraine has a relatively low permeability. The present use for agricultural purposes reflects its potential. However slow drainage



DOMINANT FACIES

▨ Dss - Layered diamicton with sand stringers

RARELY OCCURRING FACIES

▨ Dk - Massive diamicton with bedrock inclusions

Figure 27: Landform Model for Fluted Moraine (MF)

in depressions may hinder access and early germination.

6.4 RUBBLE MORAINE

Six sections in rubble moraine show the dominant facies types as being diamicton with bedrock inclusions (Dk), massive diamicton (Dm), banded diamicton and silty sand (Dbs) and folded bedrock (Bf) (see Appendix 4).

The type-section, Cm86-11 (Figure 28), is composed of massive diamicton with bedrock inclusions (Dk) and is representative of sections exposed in the steep hummocky moraine. The bedrock inclusions have well defined contacts with the diamicton sediment, and small bedrock clasts are also preserved in the till matrix. Glaciofluvial sand and gravel overlay this facies which are capped by a thin and discontinuous massive diamicton (Dm).

LANDFORM MODEL FOR RUBBLE MORAINE

The simplest model for this moraine would consist entirely of massive diamicton with bedrock inclusions (Dk). The bedrock inclusions were incorporated at the front or the base of the ice probably in a frozen state, transported over some distance and let down during slow in situ glacier meltout.

This facies (Dk) may also be associated with the facies Ds and Dbs as it is likely that in some cases, deposition may occur in stagnating ice condition. Thrusted moraine is also commonly associated with this moraine. The landform model (Figure 29) reflects the dominance of massive diamicton with bedrock inclusions, and also, that the inclusions within Dk control the general geometry of the moraine.

The left hand part of the landform represents the composition of the rubble moraine as seen in many sections: large bodies of foreign deposits included in a massive diamicton (Dk), the topography being controlled by the size and geometry of the bedrock inclusions and the diamicton forming a irregularblanket around it.

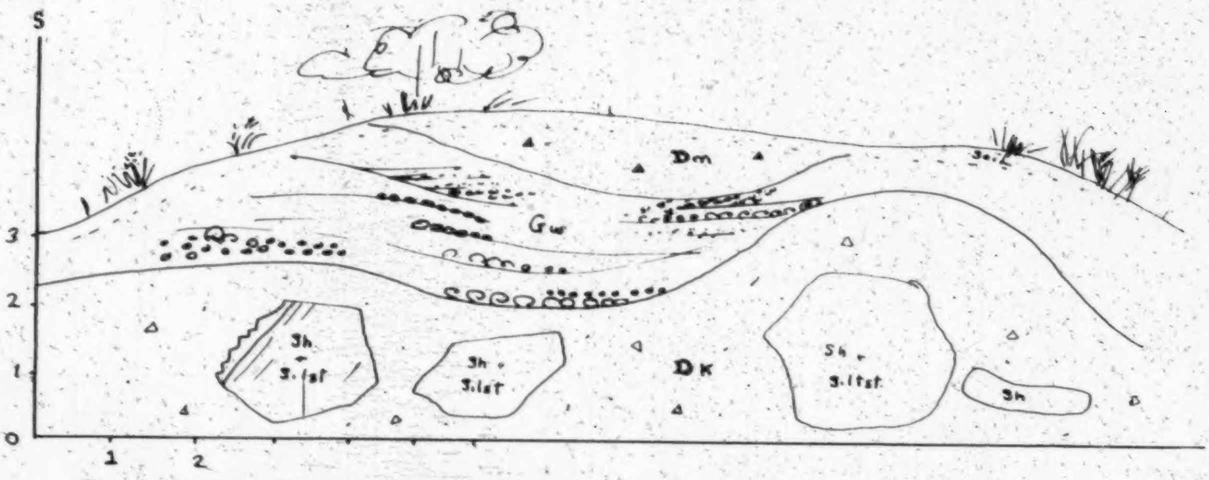
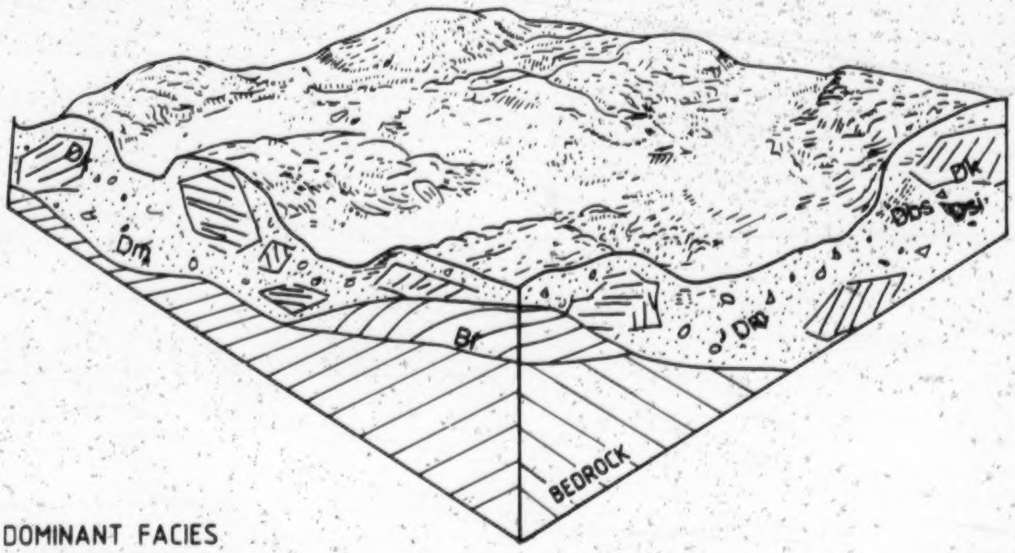

S
3
2
1
0
1
2
Dm
Gw
Dk
Sh + Siltst
Sh + Siltst
Sh + Siltst
Sh
Soil

Figure 28 Type Section for Rubble Moraine

CM86-11 **RUBBLE MORAINE**

LOCATION: TWP 48, RGE 2 W 4, SEC. 28, LSD SE 3

Dm: massive diamicton
Dk: massive diamicton with inclusions
Gw: well sorted gravel



DOMINANT FACIES

▨ Dk - Massive diamicton with bedrock inclusions

ASSOCIATED FACIES

▨ Dm - Massive diamicton

▨ Bf - Disturbed bedrock

▨ Dbs - Banded diamicton and silty sand

RARELY OCCURRING FACIES

▨ Dsi - Interbedded diamicton, sand and silt

Figure 29: Landform Model for Rubble Moraine (MR)

The center of the model represents a common association of rubble moraine and thrusted moraine. Typically, faulted or transported bedrock (Bf) is found in close vicinity to the massive diamicton with bedrock inclusions (Dk). It is not always possible to detect this association by air photo interpretation only.

The right hand side of the model represents the association of stagnant ice moraine and rubble moraine. The massive diamicton with bedrock inclusions (Dk) is still the dominant facies and controls the morphology of the terrain but the landform is also the result of depositon by stagnant ice. Facies associated with ice stagnation (Dm, Dbs, Ds and Dsi) are therefore included in this part of the model. These other facies can sometimes be assumed from air photograph interpretation but in most cases, field checking is necessary to confirm their presence.

APPLIED ASPECTS

At shallow depth, dramatic changes of physical properties can be expected, particularly at the crests of the hills and ridges where bedrock inclusions may outcrop. The sides and low surface between ridges are mostly covered by a diamicton blanket which have a narrow range in variation of physical properties.

If the bedrock inclusion is sandstone, the permeability will be much higher than that of the surrounding diamicton and water retention capacity much lower. If the inclusion consists of shale, as is often the case north of the North Saskatchewan River, the disturbed shale is likely to be crumbly, jointed and blocky and therefore, would also have a higher permeability and lower water retention capacity than the host diamicton.

Foreign bodies of unpredictable geometry and size can be observed in most sections through rubble moraine. The variation of sediments and the unpredictability of their distribution may present problems during excavation (also see Table 10). These inclusions are rarely connected and although very large, do not extend much more than 10 of metres. This results in variations of permeability locally but contamination in cases of spills is unlikely to spread over large distances unless the porous inclusions provide direct flow path into an aquifer. Joints and faults either in the diamicton or in the disturbed bedrock could greatly increase the permeability of the moraine and could increase considerably the risk of contamination.

In cases of high relief rubble moraine, the presence of large bedrock inclusions can often be detected from air photo interpretation. In areas of lower relief drilling is sometimes required to confirm the presence and nature of the inclusions. Usually inclusions of older glaciofluvial or glacial deposits can best be identified in the field.

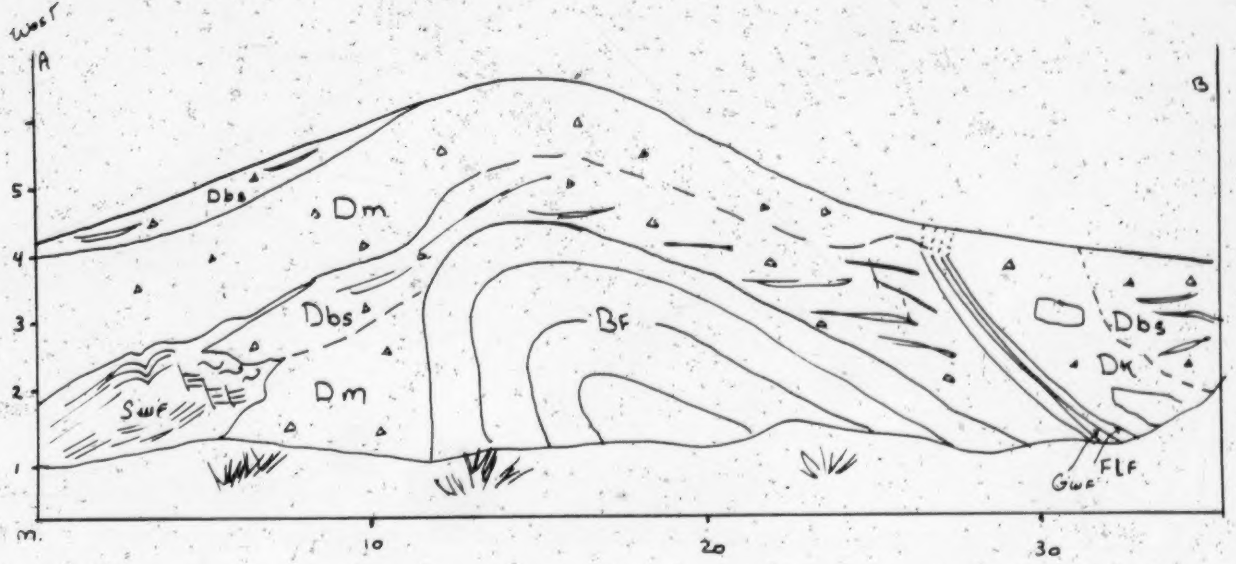
6.5 MT-GLACIOTECTONIC MORAINE

Eight sections were described for this map unit. The dominant facies types were Bf and Dm, with frequent occurrences of Dk and Dbs. Associated deposits such as sand and gravel commonly showed faulting and folding.

The composition of this glaciotectonic moraine varies greatly, and all eight sections are briefly summarized here. Section 86-2 (see Appendix 4) consists of ironstone and siltstone beds which are tilted and broken. It is very common to find sections entirely composed of disturbed bedrock. In other cases, as in sections CM84-9, CM84-6, CM82-65, CM82-240 and CM82-239 (see Appendix 4), the folded or faulted bedrock is overlain by a discontinuous massive diamicton (Dm) or diamicton with bedrock inclusions (Dk). The presence of small bedrock inclusions is very common in areas were the diamicton blanket is thicker than 1 metre and in areas where thrusted moraine is associated with rubble moraine.

The type-section CM86-19 (Figure 30) and section CM86-17 (Appendix 4), show facies assemblages which suggest a more complex sequence of depositional environments. It is interesting to note that these sections, or rather the landforms in

Figure 30 Type Section for Thrusted Moraine


West
A
B
5
4
3
2
1
m.
10
20
30
Dbs
Dm
Dbs
Bf
Dm
Swf
Dbs
Dk
Gwf
FLF

Dm: massive diamicton

Dk: massive diamicton with inclusions

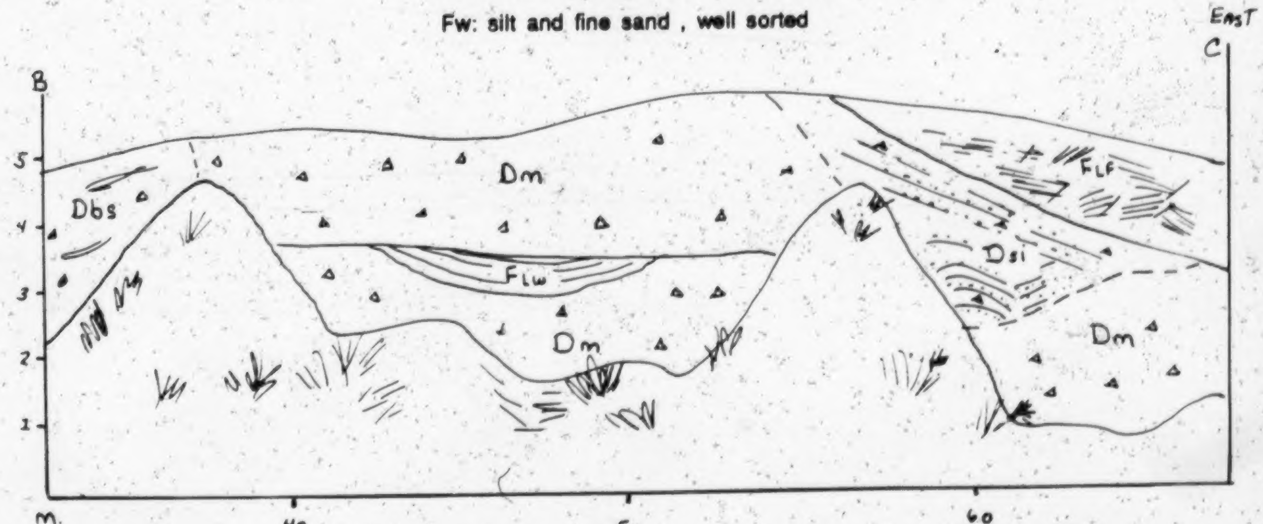
Dbs: banded diamicton and sand

Dsi: interbedded diamicton, sand and silt

Bf: disturbed bedrock

Swf: sand (fine-gr.),well sorted,faulted

Fw: silt and fine sand , well sorted


East
B
C
5
4
3
2
1
m.
40
50
60
Dbs
Dm
Flw
Dm
FLF
Dsi
Dm

SECTION CM86-19 **THRUSTED MORAINE**

LOCATION: TWP 47, RGE 2 W 4, SEC. 26, LSD SW 4 which they are cut, were identified as thrusted moraine after ground checking but were not evidently so by looking at the air photos where they simply presented the appearance of bedrock ridges with diamicton blankets or hummocky moraine.

Section CM86-17 contains two large bedrock masses that show folded and broken beds of siltstone and ironstone flanked by bodies of well stratified fine sand beds which also show faulting, folding and injection features.

CM86-19 (Figure 30), the type-section, is the most complex section described in this moraine type. The bulk of the section consists of folded bedrock (Bf) surrounded by massive diamicton (Dm), diamicton with bedrock inclusions (Dk), banded diamicton and silty sand (Dbs). Adjacent to the deformed bedrock are small bodies of silt and clay, and fine grained well sorted sediment showing micro folding and faulting and slickensided surfaces. These sorted sediments were probably part of advancing proglacial deposits and were affected by the glaciotectonic pressure at the ice front just as the bedrock was. The presence of Dbs suggests the presence of slow melting ice surrounding the deformed bedrock body. The inclusions in the diamicton are probably derived from local bedrock and were let down as the ice melted.

Glaciotectonism is related to specific geological, topographical or hydrological conditions which foster elevated pore pressure and reduction in shear strength of a material under or in front of an advancing ice sheet (Bluemle and Clayton, 1984). According to Moran et al. (1980) "Glacial-thrust terrain formed where the glacier was frozen to the substrate and where elevated pore-pressure decreased the shear strength of the substrate to a value less than that applied by the glacier". When permeable material is confined between impermeable sediments and subjected to the pressure of the advancing ice, the result is elevated pore pressure and water content, as water is pushed in from the more permeable material. This increasedd internal pressure reduces the intergranular and shear strength of the material which may then be deformed, faulted or separated more easily by the shearing force of the ice.

The degree and extent of glaciotectonic disturbance is directly linked to the type of bedrock or unconsolidated deposits being eroded. For example, shale will respond to lateral and vertical pressures differently than a sandstone interspaced with lithified ironstone beds which will also behaves very differently than a saturated, frozen proglacial sand deposit. Frozen layers of sediments may also act as an impermeable boundary. Groundwater systems will be affected by glaciation as regional flow system are obstructed by the ice or frozen ground. New systems will be created in front of the ice which causes elevated pore pressure if geological conditions permit. Ruszcynska-Szenajch (1987) differentiates between glaciotectonic activity (e.g. mechanically pushed, squeezed up or dragged without incorporation in the ice) and glacio-erosional activity (detached by freezing on to the glacier and transported within ice body).

The bedrock in the Vermilion map area consists of interfingering shales, siltstone and sandstone and meet the necessary geological conditions for glaciotectonic disturbances to occur. Topographical conditions such as upward , concave surfaces, obstructions such as hills, ridges or sides of wide valleys may cause compressive ice flow conditions. In Vermilion, this was probably occurring as the original bedrock surface slopes towards the northeast and wide preglacial valleys oriented northeast-southwest. The presence of older moraine ridges and of the Blackfoot Hills may also have possibly affected ice flow conditions.

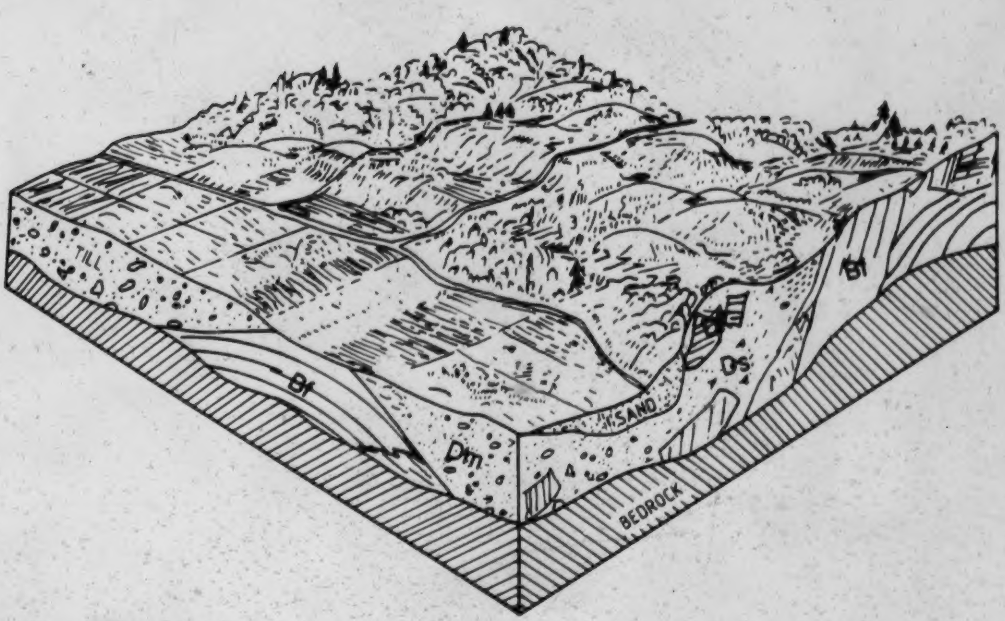
Considering 1) that the Vermilion area was subjected to more than one glacial event or advance, 2) that ice direction and shearing strength varied with each ice lobe and3) that there was a wide range of lateral and vertical competence, permeability and strength of the bedrock, the resulting glaciotectonic deformations can include folded, faulted, separated and transported, crushed and mixed bedrock. It is difficult to assess if the terrain mapped as MT are the result of one or multiple glacial advances. It is possible that at some locations the bedrock was pushed in the front of first advance, picked up by second glaciation and streamlined by a last glacial advance (e.g. the Raft Lake area). In other cases, the displaced bedrock may have been locally derived as in the Blackfoot Hills or may not show severe deformation. Glaciofluvial and glaciolacustrine sediments were also adjacent to the bedrock at the ice front and were locally deformed and included in the landform, as is the case in section CM86-19.

LANDFORM MODEL FOR GLACIALLY THRUSTED TERRAIN

The glaciotectonic moraine model could undoubtedly be subdivided into numerous subunits as it includes many expressions of glaciotectonic disturbance. Subsequent to the pressures of the advancing ice on its substratum, processes active during the deglaciation of the area can superimpose other sediments on the deformed bedrock. For example, stagnant ice conditions will result in the possible presence of sediment gravity flow deposits flanking folded bedrock, as in the type section. Although a discontinuous massive diamicton (Dm) is the most commonly associated facies, other facies (Dbs, Ds, Dsi) can be associated with this terrain. The landform model (Figure 31) attempts to illustrate these facies assemblages.

Facies Bf (disturbed bedrock) represents the simplest type of thrusted moraine, the least amount of disturbance being a shear plane at depth without evidence of transport and the most disturbance being large substratum blocks, faulted, folded or crushed and underlain by till. There is a transition zone where rubble moraine becomes an extension of the thrusted moraine. The two types of terrain are commonly associated and represented on the map as MTR, where individual rubble moraine and thrusted moraine landforms coexist or are indistinguishable at this map scale. The facies Dk and Dm then become a component of the thrusted moraine.

The presence of other facies such as banded diamicton and silty sand (Dbs) and



DOMINANT FACIES

▨ Bf - Disturbed bedrock

⁘ Dm - Massive diamicton

▨ Dk - Massive diamicton with bedrock inclusions

ASSOCIATED FACIES

▤ Dbs - Banded diamicton and silty sand

⁘ Ds - Massive diamicton and sand lenses

▨ B - Undisturbed bedrock

Figure 31: Landform Model for Thrusted Moraine (MT)

massive diamicton with sand lenses (Ds) as well as massive diamicton (Dm) are related to the deglaciation processes associated with either stagnating ice blocks or slow melt out of the retreating ice. In such cases, theses facies can mask the bedrock mass or form a discontinuous blanket.

APPLIED ASPECTS

The texture of the first metre of this moraine can vary greatly and its permeability and bearing strength will reflect these changes. The disturbed bedrock is generally weakened by crushing, faulting and shearing, can show signs of overconsolidation and usually has a variable permeability. In some cases, the crushing and fracturing of impermeable shale or hard ironstone beds will increase the permeability of the disturbed bedrock. In other cases, as explained in Fenton and Pawlowicz (in press) permeability is decreased as the water "flow path may be disturbed or sealed during deformation".

If the landform is formed entirely of a single sediment type, the geotechnical behavior is predictable at depths shallower than 2 metres. When the deformed bedrock is covered by a discontinuous diamicton blanket, it is difficult to assess the exact depth and configuration of the contact between the bedrock and the diamicton and as a result it is difficult to predict the variations of physical properties.

Residential development is possible but because the extension, severity and depth of the disturbance is not always obviously determined by the observations of exposures alone, site from field observations, borehole investigation should be conducted and include an adequate number of test holes. Weak planes may cause failure during excavations, particular if shearing has taken place during the deformation. In many cases, topography alone will hinder any agricultural development. The deformed bedrock generally has a higher permeability than undisturbed bedrock which may increase the speed and extension of contamination of the soil and possibly of groundwater. Joints and faults either in the diamicton or in the disturbed bedrock could greatly increase the permeability of the moraine and could increase considerably the risk of contamination (also see Table 10).

CHAPTER 7 DEGLACIATION HISTORY

7.1 INTRODUCTION

The Vermilion area lies behind the southern limit of the last glaciation (Prest, 1984) and according to the lithostratigraphic record, possibly four major glacial events took place in the Vermilion-east area.

Previous to any glaciation, bedrock consisting of Cretaceous shale, siltstone and sandstone was exposed at the surface. During the Laramide orogeny, uplift of the western part of Alberta created a network of rivers flowing eastward which eroded bedrock and deposited gravels composed mainly of hard sandstone, quartzite, chert and limestone. Such gravels, known as Saskatchewan sand and gravel, are now found in the bottoms of the preglacial valleys resting unconformably on the Cretaceous bedrock. Stratified Unit A or at least its lowermost component was probably deposited by late Tertiary streams. It is possible that an upper stratum of this unit is associated with the advancing proglacial deposits of the first glacial advance. In this case, they would contain far-travelled clasts from northern Alberta and would record the first glaciation in the area.

7.2 FIRST GLACIAL EVENT (OLDEST)

The oldest diamicton unit, Diamicton Unit A is correlated to till deposited by the first glaciation in the area, the Cherry Grove Glaciation of Pre-Wisconsinan age (Andriashek, 1985). Although it is not detected south and west of the Landonville Ridge, this does not necessarily indicate that it was never deposited, merely that is was not preserved.

As the Cherry Grove glacier retreated, glaciofluvial sediments were deposited and designated as Stratified Unit B also of pre-Wisconsinan age. It is possible that Stratified Unit B may represent outwash of the following glacial event.

7.3 SECOND GLACIAL EVENT

The second glaciation, named the Fort Kent glaciation by Andriashek (1985), originated from the north and northeast of Alberta and deposited Diamicton Unit B. This unit is much thicker north and east of the Landonville Ridge and thickest north of the North Saskatchewan River which suggests either a standing ice position(s) or simply preservation of the moraines. Diamicton Unit B is preserved in some channels or depressions in the southwest portion of the map of the map but is virtually absent from the Blackfoot Hills and from the Raft Lake Lowlands.

As the ice retreated, part of Stratified Unit C was probably deposited as outwash and the exposed Diamicton Unit B was weathered to depth of 2 metres in places.

7.4 THIRD GLACIAL EVENT

Proglacial deposits of the next glacial event may be responsible for the deposition of part of Stratified Unit C. The Ardmore Glaciation (Andriashek, 1985) resulted in the deposition of the Diamicton Unit C and possibly dates from the Early Wisconsinan. This till is rich in carbonates both in the matrix and in the coarse sand fraction which suggests the incorporation of Devonian carbonates outcropping in northeastern Alberta. The Ardmore Glacier possibly eroded previous diamictons in the southwest portion of map and is responsible for glaciotectonism in the vicinity of Frog Lake and in the Blackfoot Hills.

Diamicton Unit C is found throughout the mapped area, and is thickest east of Frog Lake . A ridge like feature trending west-east in townships 50 and 51 may indicate a frontal moraine. Thick diamicton is also present under the Landonville Ridge but there is not enough evidence to interpret this landform as resulting from stationary ice of the Ardmore glacier. Diamicton Unit C is thin and discontinuous west of range 6 and between townships 54 to 57 where it may have been eroded and in the Blackfoot Hills where it is associated with glaciotectonic activity.

As the Ardmore glacier retreated, meltwater deposited part of the sand and gravel of Stratified Unit D. The following nonglacial interval may have been longer or have experienced milder and more humid conditions than the previous nonnglacial intervals, as the surface of the Diamicton Unit C is weathered to a depth of 2.5 metres and has a well developed system of iron-stained joints.

7.5 LAST GLACIAL EVENT (YOUNGEST)

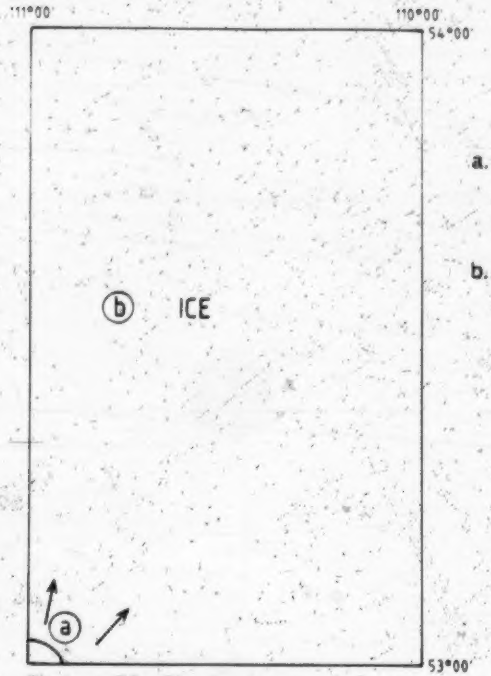
Based on stratigraphic interpretations and surface geology, it is evident that a complex sequence of deglaciation was involved. It is generally accepted that the uppermost diamicton units of the Vermilion map area (Diamicton Units D and E, possibly F) were deposited during the late Wisconsinan Lostwood Glaciation (Fenton, 1984) and deglaciated by approximately 12 Ka (Dyke and Prest, 1987).

Advance of the glacier over the mapped area probably contributed to sand and gravel of the Stratified Unit D. This glaciation is also responsible for some of the glaciotectonic disturbance and erosion of most of diamicton in the Blackfoot Hills.

The first stage of ice retreat in the Vermilion-east area is marked by a stationary front at Buffalo Creek. This ice body was retreating towards the northeast and deposited Diamicton Unit D.(Figure 32).

From this point, the active ice retreated to a position outlined by Grizzly Bear Creek where drainage of meltwater joined the Battle River (Figure 33). Between those two positions, hummocky moraine occurs and suggests slow melting of stagnant ice blocks. Around Weeks Lake, a fluting field oriented towards the southwest is visible under a discontinuous veneer of lacustrine and stagnant ice sediments (Figure 33) indicating that ice flow was from the northeast. Ice retreat towards the northeast is also suggested by the general southwest-northeast orientation of eskers exposed in the Vermilion lowland and Blackfoot Hills.

The third position of the active ice front is well defined by the Landonville Ridge and by associated meltwater channels and glaciofluvial ice contact deposits on


111°00'
110°00'
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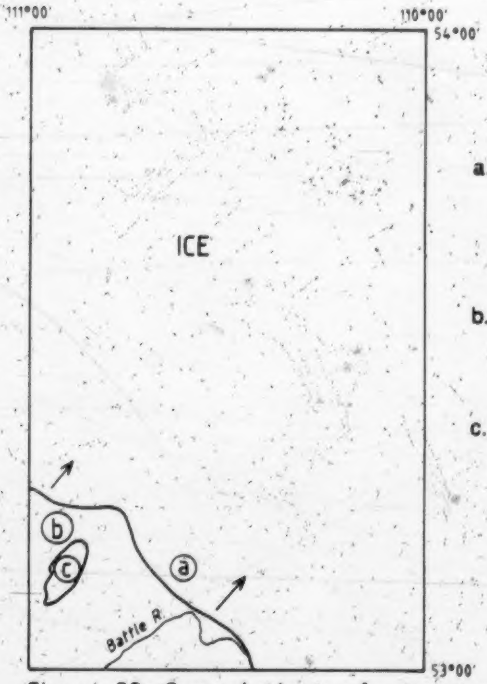
ICE
b
a
53°00'

Figure 32: First stage of ice retreat

a. Stationary ice front north of meltwater channel Buffalo Creek

b. Ice is retreating toward the northeast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Battle R.
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Figure 33: Second stage of ice retreat

a. Stationary front north of meltwater channels Grizzly Bear Creek and Battle River.

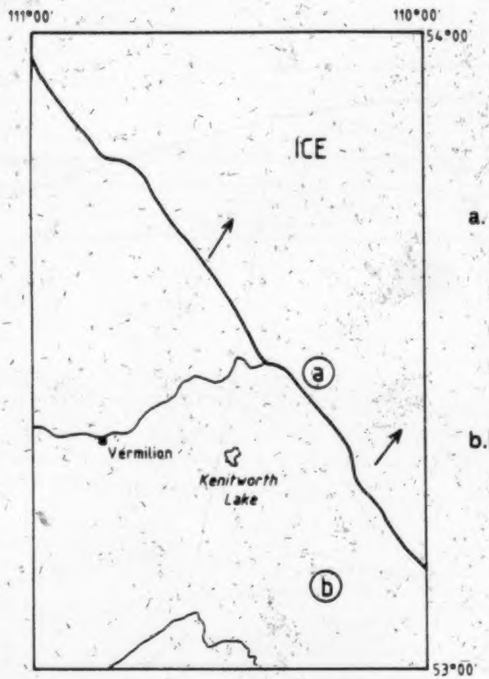
b. Stagnant ice blocks slowly down melting

c. Flutes trending southwest are exposed the west flank of the ridge. (Figure 34). At this stage, an ice segment was probably cut from the main ice body and remained on the Vermilion Lowlands. Stagnant ice moraine with fairly well defined and thin glaciofluvial deposits overlay the previous deposits around the stagnant ice position.

From this third ice position, parallel ice fronts can be traced west of Altimose Creek, Irish Creek and Big Gully Creek (Figure 35). The right-angle bends of the Vermilion River result from drainage blockage occurring during some of the stationary ice front positions. At that stage, also, the block of ice from the northwest was still positioned in the Vermilion Lowland and slowly melting. This ice position was estimated by Dyke and Prest (1987) to have occurred at around 12 Ka.

The ice retreated further north and east to a position parallel to the Moosehills Creek, the North Saskatchewan River and Pastachaw Lakes (Figure 36). At that point, a rapidly flowing ice tongue from the northwest glacially streamlined and modified the surface of Irish Creek Plain and stopped south of Lloydminster. In the Raft Lake area, faint streamlining of the ridge crests on the rubble moraine west of the Landonville Ridge towards the southeast suggests that this ice body flowed over the Landonville Ridge . Further south, the ice contact deposits west of the ridge are preserved. They do not show major faulting, and therefore, it is likely that the influence fromo this ice lobe stopped north of the Vermilion River. Regional mapping by Shetsen (1990) does not show fluting striking S40^{o} E south of the Irish Creek Plain and it follows that this ice did not expand much further.

Another possible explanation for the flutes is the occurrence of subglacial flood events which would have eroded the surface sediment in this corridor into ridges and grooves (Shaw, Kvill and Rains, 1989). The erosional remnant ridges could be subsequently streamlined by the ice. Either theory requires ice flowing in a southeastern direction. No evidence of glaciofluvial deposition associated which such event is present in close vicinity of the flutes but further work south of the map area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ICE
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Vermilion
Kenilworth Lake
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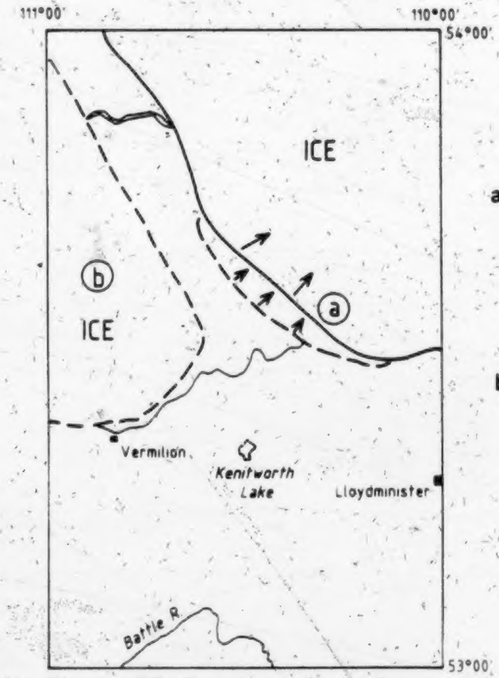
53°00'

Figure 34: Third stage of ice retreat

a. Stationary ice front at Landonville ridge, drainage through Altimose, Death and Blackfoot creeks and deposition of ice -contact sediments west of the ridge.

b. Exposure of eskers with northeast-southwest orientation in Blackfoot Hills.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ICE
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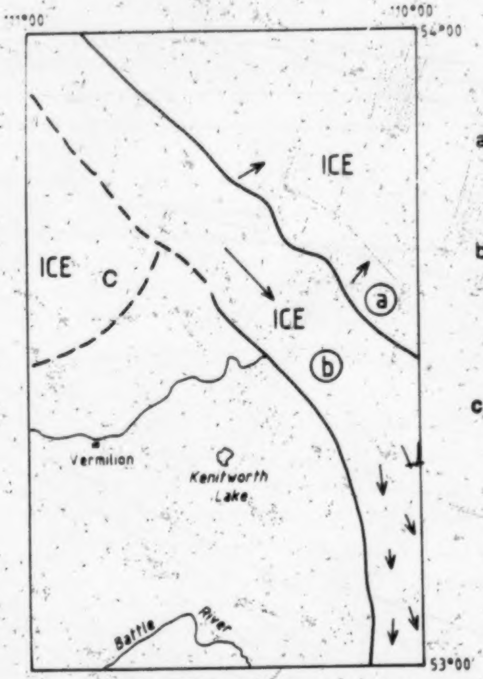
ICE
a
Vermilion
Kenilworth Lake
Lloydminister
Battle R.
53°00'

Figure 35: Fourth stage of ice retreat

a. Stationary ice front position north of and drainage of meltwater through Moosehill and Irish Creeks, St-Yves Lakes and Big Gully Creek

b. Stagnant ice block melting west of Landonville Ridge


111°00'
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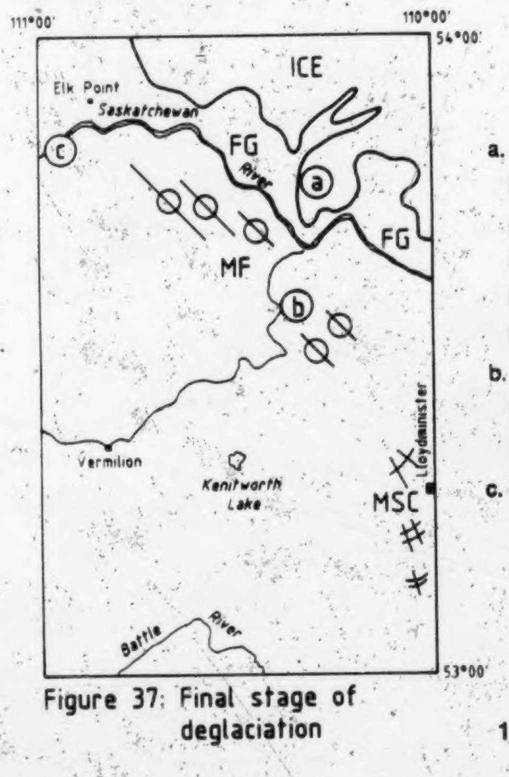
ICE
ICE
c
ICE
a
b
Vermilion
Kenilworth Lake
Battle River
53°00'

a. Stationary front of eastern lobe northeast of Moosehill Creek and Pastachaw Lakes.

b. Ice from the northwest flow into Irish Creek Plains, is confined by the two ice block and overlies deposits of northeast lobe

c. Stagnant ice block melting west of Landonville Ridge

Figure 36: Fifth stage of ice retreat


111°00'
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ICE
Elk Point
Saskatchewan
c
FG
River
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FG
MF
b
Vermilion
Kenilworth Lake
Lloydminster
MSC
Battle River
53°00'

a. Eastern ice lobe slowly melting as large blocks east of Frog Lake, glaciofluvial deposition north of N. Saskatchewan River and erosion of bedrock surface around Tulliby Lake by meltwater.

b. Rapid melting of ice tongue which deposits ice crevasse fillings, flutes are exposed.

c. Western ice block has possibly disappeared from the mapped area

Figure 37: Final stage of deglaciation

might provide more clues as to the possibility of such subglacial activity.

During the last stage of deglaciation (Figure 37), the western ice block decreased in size and the ice stream retreated after having deposited ice crevasse fillings and thin stagnant ice moraine in the southern part of the Irish Creek Plain. Minor ponding might have occurred locally at the surface of the melting ice as indicated by small and thin deposits of fine-grained sediments overlying the flutes. The sandy nature of the stratigraphic unit deposited by ice body, Diamicton Unit E, might be related to the fact that deposits previously deposited by the eastern lobe were possible overridden and remobilized.

Also in that final stage of deglaciation, glaciofluvial deposits overlying and cutting channels through the glacial flutes and the development of meltwater channels in the Cabin Lake area, suggest that the eastern lobe was still sitting west of the Pastachaw-North Saskatchewan-Moosehill position. Melting of the eastern glacier continued to leave stagnant ice moraine, poorly developed meltwater drainage pattern in the Frog Lake uplands, the erosional surface in Tulliby Lake area and large glaciofluvial deposits in the Laurier Lake lowland.

According to Christiansen 's (1979) model of deglaciation for southern Saskatchewan and the surrounding area and to Dyke and Prest(1987), the Vermilion-east area would have been free of ice between 11.5 Ka to 10 Ka ago.

CHAPTER 8 CONCLUSIONS

This chapter summarizes the findings related to the main objectives of the thesis and comments on directions for further research.

The Quaternary lithostratigraphy as reconstructed for the Vermilion area identifies a preglacial stratified unit, six diamicton units associated with 4 major glacial events and three stratified units related to the corresponding interglacial intervals. The stratigraphic position and mineralogy of the coarse sand fraction were the most reliable correlation tools. Based on lihtostratigraphic correlations with the units of Andriashek (1985), the oldest of the glacial event could date from the pre-Wisconsinan, the following glaciations from the Early Wisconsinan to Late Wisconsinan.

The last glaciers retreated from the Vermilion-east area in a complex sequence involving three ice bodies or lobes. The last glacier to occupy the area retreated towards the northeast probably 12,500 Ka ago.

The surficial geology mapping conducted in the Vermilion area was augmented by a description of landforms based on lithofacies types. Seven facies were described as the major components of four glacial landforms, and all of these facies contain diamicton as a main textural component. The combination of facies descriptions and interpretations, and section description were used to develop landform model for stagnant ice moraine, fluted moraine, rubble moraine and thrusted moraine.

This approach to terrain description is an attempt to improve the information provided by traditional surface mapping. The models supplement the map with a detailed description of the internal composition of the moraine and of the expected variability. It is obvious that all facies characteristic of a specific depositional environment are not always present within a section. Similar depositional environmnents can be responsible for the deposition of different facies types or for different assemblages but the facies interpretation should be consistant with this environment. In other cases, a massive diamicton may present a different texture and still present the same facies characteristics. The formulation of landform models allows for the identification of such differences and prepares the map user for the range of predicted or expected facies types within the landforms. The complex sequence of processes active in the glacial environment can produce various types of facies assemblages within a moraine type. The development of models helps understand and predict those changes.

During most mapping exercises, the rapid pace of surveying does not always allow the necessary time to describe sections in sufficient detailt to develop a facies scheme and landform models. A sedimentological approach to the description of selected sections increases the understanding and knowledge of morainic composition. Although it adds time and costs to a survey, the cumulative information and understanding gained through the development of such models is valuable and is a recommended addition to the field component of surveys.

As interest int the environment increases, greater concerns about issues such as soil and water contamination and disposal of various types of waste, become important factors when policy decisions are made. This is reflected by the greater effort to assign land uses based on the physical capacity of the land and by the prevention and management of hazards such as spill of contaminated fluids and disposal of solid waste. A better knowledge of landform compositions and their expected range and variation of properties, expressed as a model, can become an important tool for use in the decision making process.

The attempt to describe landforms in terms of facies can also benefit the Quaternary stratigrapher. The development of landform models elucidates the vertical and lateral facies distribution. This knowledge if linked with analytical data could help stratigraphers focus on the most meaningful stratigraphic tools, for example whether texture or coarse sand mineralogy are diagnostic of a stratigraphic unit.

Plate 1. Aeolian dune filed and streamlined moraine in Irish Creek Plain.

Plate 2. Fluvial sand, excavation for the Meridian Bridge foundations, North Saskatchewan River

Plate 3. Glaciofluvial sand and gravel, located south of Vermilion.

Plate 4. View of an Esker located south of Lloydminster.

Plate 6. Ice crevasse filling and low relief stagnant ice moraine located south of Lloydminster.

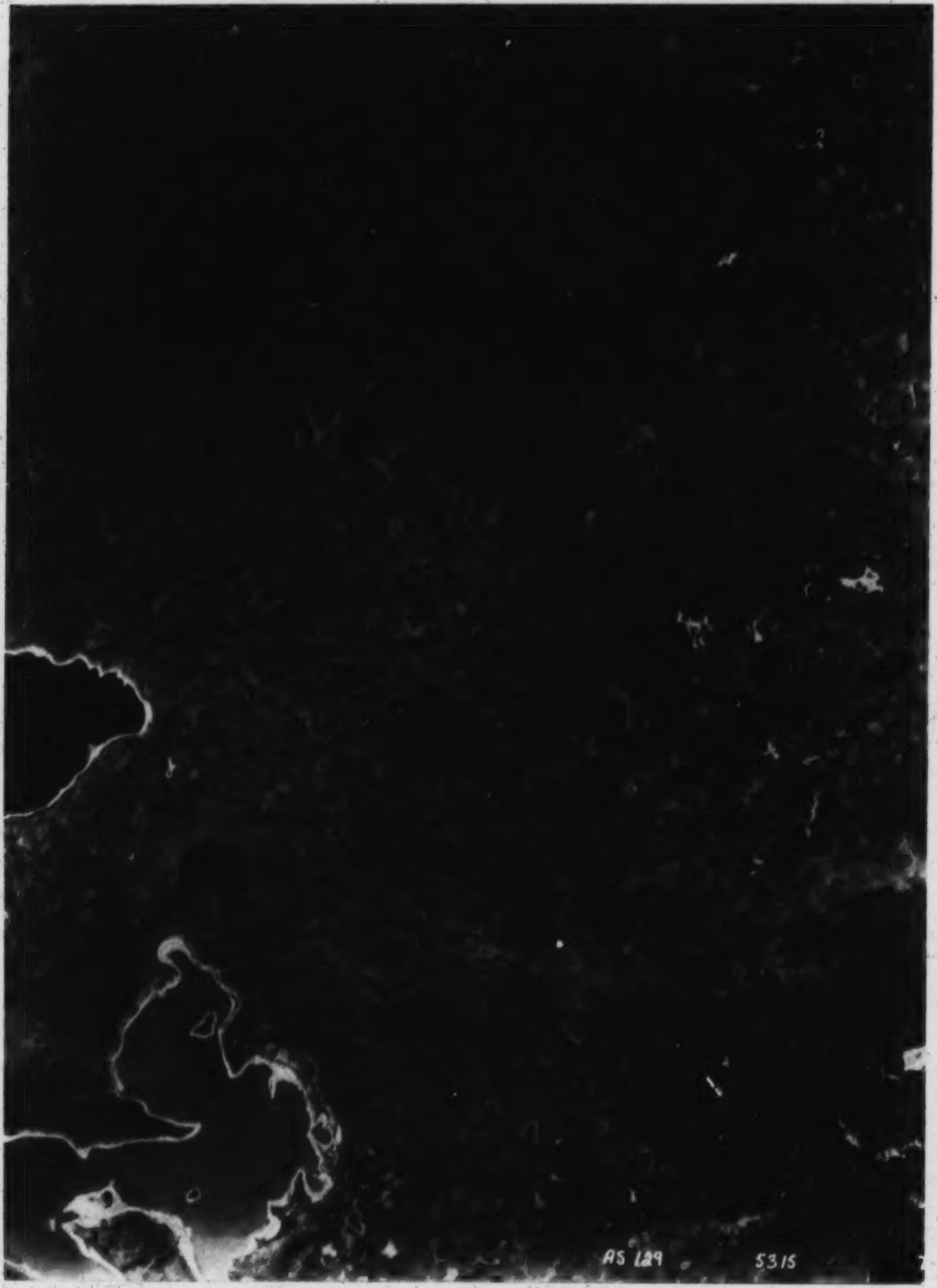

Plate 7. High relief stagnat ice moraine located east of Frog Lake

Plate 8. Cross-section through a thrusted moraine ridge showing disturbed sandstone overlain by massive diamicton, located in the Blackfoot Hills.

Plate 9. Massive diamicton facies, section Cm86-8.

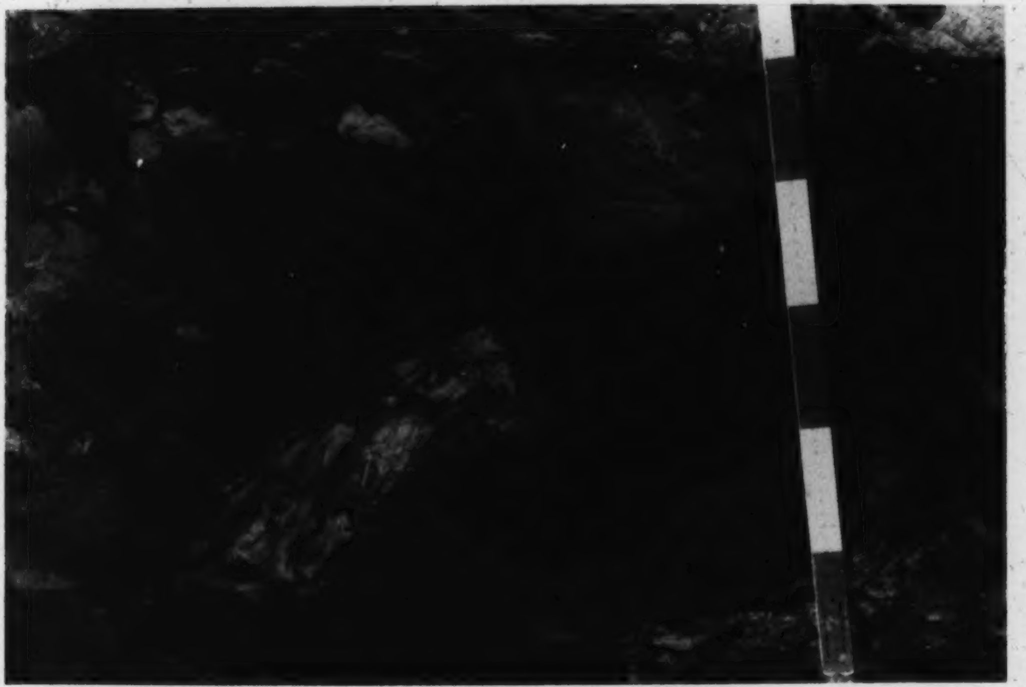

Plate 10. Massive diamicton with sand lenses, section CM82-99.

Plate 11. Diamicton with sand stringers, section CM86-13.

Plate 12a. Banded diamicton and silty sand facies, section CM84-5.

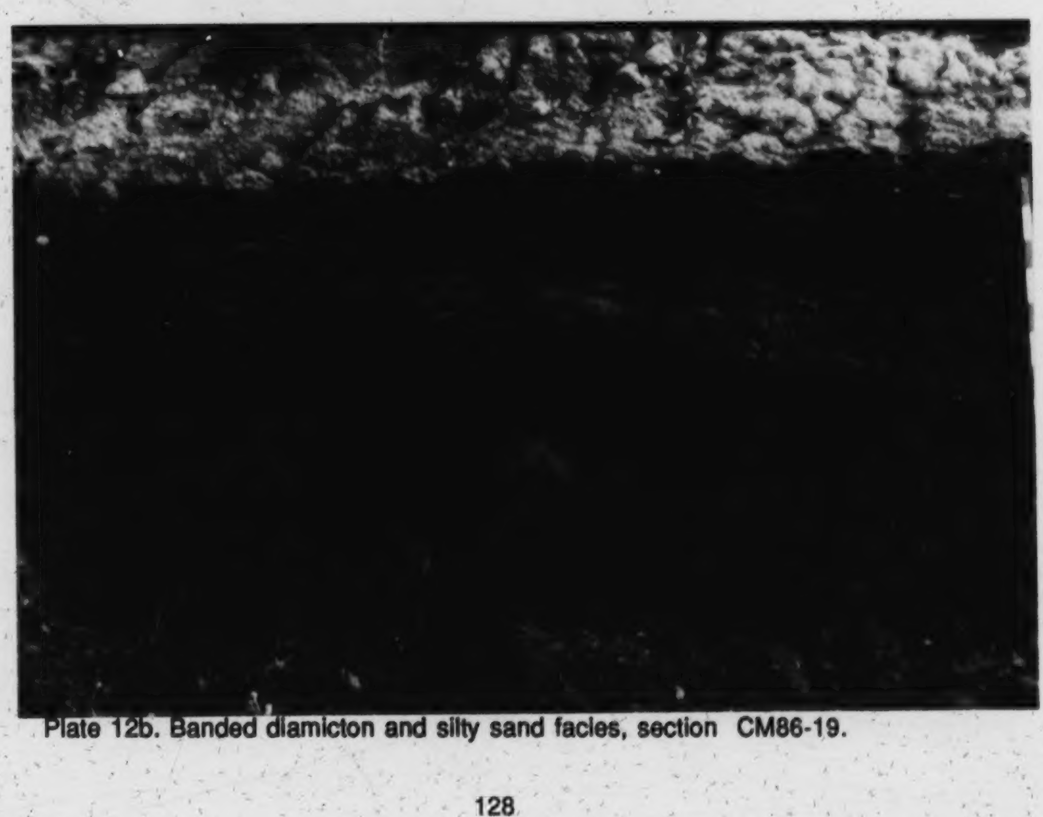

Plate 12b. Banded diamicton and silty sand facies, section CM86-19.

15 16 17 18 19 2
0 31

Plate 13. Interbedded diamicton, silt and sand facies, section CM83-103

Plate 14. Massive diamicton with bedrock inclusions, section CM82-51

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APPENDIX 1 DESCRIPTION OF SURFICIAL GEOLOGY COMPLEX UNITS

APPENDIX 1 DESCRIPTION OF SURFICIAL GEOLOGY COMPLEX UNITS

UNDIVIDED GLACIOFLUVIAL AND GLACIOLACUSTRINE DEPOSITS (FLG)

This unit notation is used either where the two map units cannot be separated at this scale or where it is not clear which processes were dominant. The sediments are usually well sorted silt to medium-grained sand with occasional coarser fragments. They often have a poorly stratified massive appearance. These deposits are usually thin and present a low undulating to hummocky topography.

ERODED MORAINE AND FLUTED MORAINE COMPLEX (MFE)

Terrain in which two units are inseparable because of similar appearance or the small area covered by the individual units. It is composed of diamicton with local, thin sand and gravel. Morphology is hummocky to rolling with low relief. This unit is of minor significance and is present mostly north and west of Wavy lake.

NORMAL MORAINE UNDIVIDED (MNU)

Terrain in which the two units are inseparable due to a similar appearance or the small area covered by the individual units. Unit is generally composed entirely of diamicton or diamicton overlying bedrock. Morphology is hummocky to rolling with low to moderate relief.

RUBBLE MORAINE AND FLUTED MORAINE COMPLEX (MRF)

Terrain in which the two units are inseparable due to a similar appearance or the small area covered by the individual units. Unit is generally composed entirely of diamicton or diamicton with inclusions of bedrock. Morphology is hummocky to undulating with low to moderate relief and streamlined parallel to the ice flow direction.

RUBBLE MORAINE AND TRANSVERSE MORAINE COMPLEX (MRN)

Terrain in which the two units are inseparable due to a similar appearance or the small area covered by the individual units. Unit is generally composed entirely of diamicton or diamicton on bedrock. Morphology is hummocky to rolling with low to moderate relief. In most case the low relief map units did not allow sufficient exposures to define if the bedrock cores were in situ or not.

RUBBLE MORAINE AND UNDIVIDED MORAINE COMPLEX (MRU)

Terrain in which the two units are inseparable due to a similar appearance or the small area covered by the individual units. Unit is generally composed entirely of diamicton with inclusions of bedrock. Morphology is hummocky to rolling with low to moderate relief.

STAGNANT ICE MORAINE AND ERODED MORAINE COMPLEX (MSE)

Two units are inseparable due to a similar appearance or the small area covered by individual units. It is composed mainly of till with local sand lenses or stringers and very often the diamicton had a sandier composition for the first metres. Morphology is hummocky to rolling with low to moderate relief. Thickness is variable but generally less than 3 metres.

STAGNANT ICE MORAINE AND FLUTED MORAINE COMPLEX (MSF)

Two units are inseparable due to a similar appearance or the small area covered by individual units and composed mainly of till with local sand lenses or stringers. Morphology is hummocky to rolling with low to moderate relief and minor streamlined features parallel to the ice flow direction. Thickness is variable but generally less than 2 metres.

NORMAL AND ICE DISINTEGRATION MORAINE COMPLEX (MSN)

Two units are inseparable due to small area covered by individual units or to a similar appearance. Composed mainly of diamicton and may contains large bedrock inclusions of be composed of diamicton overlying bedrock. Morphology is usually low, hummocky to rolling. Thickness of the unit is generally more than 3 metres. This unit covers a small percentage of the area.

RUBBLE AND ICE DISINTEGRATION MORAINE COMPLEX(MSR)

Two units are inseparable due to small ara covered by individual units or to a similar appearance. . They are composed mainly of diamicton and may contains large inclusions of displaced bedrock or sand and gravel. Topography is usually low to moderate and hummocky. Thickness of the unit is generally more than 3 metres. This unit covers a small percentage of the area.

STAGNANT ICE MORAINE AND UNDIVIDED ICE MORAINE COMPLEX (MSU)

This terrain is called undivided because it has no diagnostic features to place it in one of the subdivisions of stagnant ice moraine described below or it is a complex of two or more types of stagnant ice moraine that are inseparable at the map scale used. It is composed mainly of diamicton as described in MS with local sand lenses or stringers. Morphology is hummocky to rolling with low to moderate relief. It at least as thick as its relief.

THRUSTED MORAINE AND ERODED MORAINE COMPLEX (MTE)

Units are inseparable due to a similar appearance or to the small area covered by individual unit. Composition is similar to that of thrust moraine. When a polygon labelled MTUk is located directly down from it, it indicated the source of the probable source of the thrusted hill. Morphology is hummocky to rolling with low to moderate relief. Thickness is variable but generally more than 3 metres.

THRUSTED MORAINE AND RUBBLE MORAINE COMPLEX (MTR)

Units are inseparable due to a similar appearance or to the small area covered by individual units. Composition is similar to that of thrust moraine. Morphology is hummocky to rolling with moderate relief, with short arcuate ridges and knobs and associated depressions. Thickness is variable but generally more than 3 metres. This unit covers most of the Raft Lake physiographic unit and is also present in the Blackfoot Hills.

THRUST MORAINE AND UNDIVIDED MORAINE COMPLEX (MTU)

Units are inseparable due to a similar appearance or to the small area covered by individual unit. Composition is similar to that of thrust moraine. Morphology is hummocky to rolling with low to moderate relief. Thickness is variable but generally more than 3 metres.

MU-MORAINE UNDIVIDED

Terrain without the diagnostic features of any of the preceding moraine types or showing three or more types of moraines inseparable at this scale of the map. It is composed mainly of diamicton but may include minor sand, silt, clay or gravel of glaciofluvial or glaciolacustrine origin. Morphology is hummocky to rolling usually with low to moderate relief. Thickness is usually more than 2 metres. Ponding in MU terrain is usually not as dense and present a different appearance than the drainage pattern of stagnant ice terrain. The hummocks are smooth and do not present ridge-like features or central depression. This type of moraine has often been called ground moraine.because of its lacks of distinguishing features. When the polygon to which this symbol is attached covers a small surface, it is more likely to indicate a complex moraine unit that cannot be separated at this scale.

UNDIVIDED MORAINE AND ERODED MORAINE COMPLEX (MUE)

Units are inseparable due to a similar appearance or to the small area covered by individual unit. Morphology is hummocky with low to moderate relief. Thickness is variable but generally more than 3 metres.

APPENDIX 2. DIAMICTON UNITS DATA SUMMARY

DIAMICTON UNIT B ANALYTICAL PROPERTIES

				C. SD		COAR SE		SAND		MINER ALOGY			
ARC #	DEPTH IN M.	SD%	CLAY%	1-2MM %	CO3 %	CR%	Q%	LST%	DST%	LOC%	QRTZ%	QSS%	Q/C
78-1	55-58	37.6	37.0	1.2	4.0	46.6	42.8	2.0	1.7	5.3	0.5	0.9	0.9
80-3	13-29	35.8	37.6	2.0		47.7	36.8	2.8	5.7	3.7	0.8	1.4	0.8
81-7	40+	26.8	37.9	1.2									
81-14	41.1-45	33.4	31.2	2.0	7.0								
81-17	45-51	49.7	28.8	2.5	10.5	45.6	40.1	3.1	2.0	6.1	2.7	0.4	0.9
MEAN		36.7	34.5	1.8	7.2	46.6	39.9	2.6	3.1	5.0	1.3	0.9	0.9
STDEV		7.5	3.8	0.5	2.7	0.9	2.5	0.5	1.8	1.0	1.0	0.4	0.1

DIAMICTON UNIT C - ANALYTICAL PROPERTIES

						COARSE		SAND		MINERALOGY			
BOREH	DEPTH IN M.	SD%	CLAY%	1-2MM %	CO3 %	CR%	Q%	LST%	DST%	LOC%	QRTZ'	QSS%	Q/C
78-1	45-55	28.0	45.5	1.0	8.0	46.1	30.7	10.2	4.9	4.6	0.4	0.6	0.7
78-3	10-13	31.5	45.0		7.6	54.5	33.4	2.1	5.9	0.9			0.6
78-4	19-26				11.0	63.8	29.8	0.6	3.4				
78-16	9-12	35.7	34.6	2.1		40.6	40.3	6.5	8.5	2.2			
79-46	1-14	45.0	30.6	3.0									
79-47	15-24	41.2	34.4	1.8	8.8								
79-49	45-52	38.6	36.5	1.9	9.9	57.1	25.2	4.0	7.1	3.9	1.2	0.9	0.4
80-3	1-12	49.4	26.1	3.7	10.0	45.4	35.6	3.4	5.9	6.6	1.0	1.3	0.8
80-4	8-11	NA	NA	NA	10.4	52.6	24.5	5.1	6.8	7.6	0.9	0.9	0.5
80-6	13-22	44.7	26.6	3.0	9.3								
80-7	7-14	38.0	26.8	1.6	10.6	43.9	26.4	5.1	8.9	10.4	1.6	0.8	0.6
80-9	1-11	32.3	38.0	1.3	12.5	55.3	28.3	3.1	4.6	4.0	1.5	2.0	0.5
80-12	1-18	44.5	24.3	2.9	11.3	53.2	21.9	9.1	3.9	10.3	0.9	0.0	0.5
80-14	19-22	50.9	22.7	2.6	7.1	52.0	35.2	3.7	1.8	2.9	2.0	1.6	0.7
80-15	8-16	35.6	33.6	1.6	12.0	53.9	28.0	8.3	1.4	2.3	3.6	1.2	0.5
80-22		36.4	37.1	1.7	9.8								
80-25	14-19	33.9	27.6	1.7	10.0	49.0	24.6	9.3	4.5	7.4	1.2	0.5	0.5
80-26	6.2-13	38.2	29.1	1.6	8.6	54.2	30.1	3.5	2.6	4.6	1.5	1.6	0.6
80-27	8-13	36.3	30.9	1.1	8.2	44.5	23.6	9.9	4.8	10.0	1.1	0.9	0.5
80-28	26-38	47.5	24.7	2.1	10.0	51.3	27.9	6.0	8.1	4.5	1.2	0.9	0.5
80-31	27-40	39.3	35.2	2.3	10.3	48.7	30.2	6.4	6.6	3.0	0.9	0.4	0.6
80-32	6-14	48.0	32.0	2.6	11.5								
80-33	9-16	32.0	32.9	1.2	12.1								
80-34	23-45	37.9	33.2	1.3	7.7								
80-39	8.5 +	43.3	20.4	3.1	20.8								
80-41	8-12	36.8	32.8	1.6	10.1								
81-8	20-25	34.8	29.7	1.7	9.9	53.9	33.6	2.4	2.2	3.5	1.6	2.8	0.6
81-14	24-35	34.0	32.2	1.7	7.0		DD						
81-16	33-44	45.0	30.0	1.7	11.0	48.9	30.1	4.7	6.1	5.0	2.9	1.6	0.6
81-17	20-40	32.5	40.7	2.0	14.0	52.3	30.1	4.3	6.9	3.2	1.6	1.2	0.6
MEAN		**38.8**	**32.1**	**2.0**	**9.9**	**51.1**	**29.5**	**5.4**	**5.2**	**4.9**	**1.5**	**1.1**	**0.6**
STDV		5.9	6.0	0.7	1.7	5.2	4.5	2.7	2.2	2.8	0.8	0.6	0.1

DIAMICTON UNIT D - ANALYTICAL PROPERTIES

				C. SD		COAR SE		SAND		MINER ALOGY			
BOREH	DEPTH	SD%	CLAY%	1-2MM	CO3	CR%	Q%	LST%	DST%	LOC%	QRTZ%	QSS%	Q/C
	IN M.			%	%								
78-1	22-44	33.4	41.9	1.3	8.3	54.5	33.1	2.1	3.3	1.4	0.4	2.1	0.6
78-3	1-10	39.0	39.0		11.0	71.0	22.0	1.2	1.6	0.9			0.3
78-4	1-9	30.6	46.0	1.3		65.0	27.0	0.8	2.6	2.3	0.1	1.3	0.4
78-16	1-5	33.6	41.5	1.0		43.0	40.5	1.6	8.4	2.7	2.4	0.6	0.9
79-47	1-13	24.4	47.8	0.8									
79-49	3-44	34.0	38.0	1.3	7.4	58.1	29.2	2.6	2.9	3.1	2.1	0.5	0.5
80-6	1-5	30.7	41.4	1.2	6.9								
80-8	1-7	34.0	39.4	1.4	8.6	51.4	28.6	3.2	3.5	3.3	1.6	1.5	0.6
80-10	1-5	31.5	35.4	1.1		56.4	32.5	2.0	1.2	3.6	1.2	0.4	0.6
80-13	2-4	33.4	36.1	1.5	9.3	61.0	29.0	3.8	2.3	2.1	1.3	1.3	0.5
80-17		29.1	30.2	1.0		57.8	31.1	3.4	2.5	2.5	1.4	0.7	0.5
80-23		28.6	31.6	1.0		56.9	30.0	2.7	2.1	2.9	1.2	2.3	0.5
80-28	21-25	32.4	38.1	1.5	7.6	56.1	31.2	1.9	3.3	2.8	1.6	0.9	0.6
80-29	6-12	33.6	36.7	1.4	6.1								
80-30	1-10	27.7	43.2	1.2	6.8	54.4	27.4	3.7	3.2	3.1	1.3	2.9	0.5
80-31	77-24	39.1	34.2	1.6	9.2								
80-34	15-22	34.0	35.0	1.1	6.7								
80-35	SURF	29.5	33.4	0.8	8.6								
80-36	1-11	26.3	42.0	1.1									
80-37	3-10	26.1	42.6	1.0	6.9								
80-38	1-8	34.4	37.1	1.5	10.4	59.1	24.2	1.1	4.4	3.5	0.6	2.7	0.4
80-40/A	1-6	25.3	38.5	0.9	7.6								
80-40/B	1-6	25.4	46.5	0.9	7.6								
81-14	12-17	35.2	40.4	1.7	8.5								
81-16	3-30	33.0	41.0	1.8	12.5	59.0	28.6	2.0	2.9	3.0	2.9	0.8	0.5
81-17	10-18	32.8	45.0	2.1	8.0	58.1	29.9	2.7	2.9	2.0	1.8	2.1	0.5
AVE		31.4	39.3	1.2	8.3	57.5	29.6	2.3	3.1	2.6	1.4	1.4	0.5
STD		3.9	4.5	0.3	1.6	5.9	4.0	0.9	1.8	0.7	0.7	0.8	0.1

DIAMICTON UNIT E - ANALYTICAL PROPERTIES

				C. SD		COARSE SAND MINERALOGY							
BOREH	DEPTH IN M.	SD%	CLAY%	1-2MM %	CO3 %	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS%	Q/C
78-1	1-20	47.1	31.4		10.0	50.1	37.0	3.1	4.7	1.5			0.7
78-5		42.0	35.0	1.9		57.0	32.0	3.3	3.1	1.0			0.6
78-9	1-4	42.0	36.0		9.0								
79-49	9-14	49.9	26.8	1.6	7.3	51.8	33.4	2.9	3.0	4.4	2.1	1.8	0.6
80-25	1-8	36.3	24.2	1.4	7.1	53.2	31.9	2.3	3.3	3.9	1.4	1.4	0.6
80-26	1-6	36.6	30.5	1.5	7.7								
80-28	1-11	37.1	27.9	1.5	9.0	53.7	34.0	2.1	3.1	2.6	1.6	0.9	0.6
80-29	1-5	39.6	32.7	1.7	6.9								
80-31	1-29DO	42.5	25.2	1.0	9.1	56.9	30.0	3.1	2.9	2.8	1.9	1.9	0.5
80-33	?4-8	39.9	38.6	2.2	7.0								
80-34	1-13	41.6	27.6	1.3	6.7								
81-8	2-25	35.6	28.2	1.2	7.9	52.3	32.0	2.2	2.0	5.3	1.6	3.2	0.6
81-17	1-11	38.7	35.6	1.7	6.0	56.1	31.8	4.0	1.7	2.9	1.1	0.4	0.6
AVER		40.7	30.7	1.5	7.8	53.9	32.8	2.8	3.0	3.1	1.6	1.6	0.6
STDV		4.1	4.4	0.3	1.2	2.4	1.9	0.6	0.9	1.3	0.3	0.9	0.1

DIAMICTON UNIT F- ANALYTICAL PROPERTIES

				C. SD		COARSE SAND MINERALOGY							
BOREH	DEPTH IN M.	SD%	CLAY%	1-2MM %	CO3 %	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS%	Q/C
80-4	1-4	NA	NA	NA	7	49.4	24.8			7	1.9	2.9	0.5
80-5	1-8	28.7	25.7	1.2	7.2								
80-7	1-5	34.2	32.5	1.42	8	57.6	27.4	3.2	3.6	2.2	1.3	1.3	0.47
80-14		37.7	33.5	1.52	9.3	59.3	25.1	3.9	3.2	4.6	1	1.5	0.42
80-15		34.1	34.2	1.32	9.7	61	26	3	1	2.3	2.3	0.9	0.42
80-20	1-8	35.9	33.3	1.39	8.1	52.6	28.6	2.7	4.2	2	0.6	1.9	0.52
80-22	SURF	36.4	37.1	1.65	9.8								
80-39	1-8	35.6	28.8	1.55	8.3								
MEAN		34.66	32.16	1.44	8.43	55.98	26.38	3.20	3.00	3.62	1.42	1.70	0.47
std dev		2.69	3.48	0.14	1.01	4.33	1.43	0.44	1.21	1.94	0.61	0.68	0.04

APPENDIX 3 TEXTURAL AND MINERALOGICAL DATA FROM ALBERTA RESEARCH COUNCIL BOREHOLES

Appendix 3-Textural and Mineralogical Data from selected Alberta Research Council boreholes.

borehole r78ve1

DEPTH				TEXTURE	MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
3	diamict.	42.6	35.1	2.03	8.5	52	36	3.8	4.6	1.6	0.4	3.1
5	diamict.	46.4	29.9	2.28	12.1	54	39	2.2	2.8	1.5	0.3	0.6
6	diamict.	42.1	34.6	2.16	10.6	45	42	1.8	6.9	0.4	0.7	1.8
8	diamict.	42.9	39.5	1.85	10	51	37	3.6	3.6	1.5	0.8	2.1
10	diamict.	47.1	31.3	2.67	9.2	50	36	3.1	5.4	2.2	1.1	2.2
14	diamict.	48.9	27.6	2.66	9.5	48	40	2.7	4.4	0.8	.3	1.4
15	diamict.	47.6	29.2	2.02	9	51	32	5.9	5.0	1.7	0.8	2.1
19	diamict.	59.4	23.9	2.24	10.8	59	30	2.8	2.0	1.5	0.3	1.8
20	diamict.	47.0	32.1	1.77	9.6	52	36	2.1	3.4	0.4	0.4	4.3
22	diamict.	34.2	45.3	1.51	11	56	31	4.9	0.5	3.8	0.5	1.6
23	diamict.	31.4	44.4	1.69	8.2	61	27	3.6	3.0	3.0	1.2	0.6
24	diamict.	33.5	41.4	1.38	8.9	58	33	2.2	2.8	0.6	0.6	1.1
26	diamict.	33.5	43.0	1.21	9.2	56	34	3.1	2.5	3.5	0.0	1.0
28	diamict.	33.6	42.8	1.11	8.0	57	33	3.1	2.5	0.8	0.8	2.5
30	diamict.	26.7	41.9	0.64	6.1	58	29	2.9	2.4	1.9	1.0	0.5
32	diamict.	34.2	38.5	1.31	9.8	60	30	2.9	2.4	2.	0.2	3.6
34	diamict.	34.0	42.9	1.28	8.2	49	37	1.8	5.4	2.4	0.2	3.6
36	diamict.	35.1	43.2	1.31	9.0	53	55	1.7	3.5	2.4	0.8	2.7
38	diamict.	34.4	40.0	1.15	9.0	50	33	6.9	4.5	1.6	0.2	2.6
40	diamict.	33.7	43.5	1.21	8.3	47	36	4.5	4.5	1.6	0.0	4.7
42	diamict.	35.1	42.1	1.25	7.5	43	40	5.0	4.3	2.1	0.0	0.3
44	diamict.	36.0	37.0	3.35	8.2	63	27	4.2	2.9	0.8	0.8	1.0
45	diamict.	28.5	42.6	0.85	8.7	50	29	9.2	3.4	6.5	0.0	0.8

46	diamict.	28.5	44.5	1.06	5.9	44	29 1	10.3	7.2	4.9	0.7	0.2

borehole r78ve1 cont'd

DEPTH				TEXTURE	MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
50	diamict.	29.2	46.1	1.13	8.9	42	22	10.4	4.4	7.0	0.2	1.2
52	diamict.	18.9	51.0	0.88	9.6	43	31	13.9	6.1	4.0	0.5	0.0
54	diamict.	13.1	59.4	0.6	8.8	45	35	9.8	5.9	2.2	0.4	0.56
556	diamict.	36.8	37.5	1.24	3.7	45	47	0.0	0.0	5.3	0.7	0.9
57	diamict.	38.1	34.8	1.45	3.8	50	42	0.5	1.6	5.7	0.0	0.5
58	diamict.	37.9	38.8	0.91	5.0	44	41	3.5	1.8	6.8	0.9	1.0

borehole r78ve3

DEPTH				TEXTURE	MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	38.1	39.9	2.16	13.2	67	24	1.1	0.1	1.4	0.3	1.8
3	diamict.	39.8	38.8	1.98	11.0	67	26	1.7	2.1	0.8	0.2	0.5
4	diamict.	39.9	37.1	0.2	11.7	71	24	1.2	2.3	1.1	0.4	0.0
5	diamict.	38.8	39.0	1.88	13.6	71	22	3.4	1.3	1.0	0.8	0.4
6	diamict.	39.2	39.5	2.14	12.4	74	21	1.8	1.9	0.8	0.4	0.8
7	diamict.	37.1	38.4	1.81	15.4	76	20	0.8	0.8	0.4	0.2	0.5
10	diamict.	39.0	40.9	1.73	12.1	54	37	0.9	5.6	1.4	0.8	0.5
11	diamict.	31.5	44.8	1.22	13.1	52	37	2.2	5.6	1.5	0.2	1.7
13	diamict.	31.6	45.3	1.5	13.5	54	32	3.7	7.0	1.1	0.0	1.2

borehole r78ve4

DEPTH			TEXTURE		MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS

2	diamict.	25.6	52.2	1.41	15.0	58	29	1.6	2.3	4.3	0.2	2.83
3	diamict.	24.9	53.1	1.21	14.9	65	29	1.8	0.4	3.4	0.0	1.4
4	diamict.	26.4	49.2	1.06	15.0	69	23	0.9	2.1	3.0	0.6	1.5
5	diamict.	25.6	50.4	1.09	15.2	67	27	1.0	2.4	2.4	0.0	1.0
6	diamict.	37.8	36.6	1.60	13.5	67	26	0.4	3.0	1.0	0.0	1.2
7	diamict.	31.8	43.9	1.60	13.9	66	27	1.1	5.5	0.5	0.0	0.0
18	diamict.	27.1	41.8	1.02	13.6	62	31	.3	3.1	0.3	0.0	1.6
19	diamict.	24.4	46.5	0.80	14.6	64	29	0.4	4.0	1.5	0.4	0.4
20	diamict.	25.9	45.5	1.07		63	30	0.4	3.8	1.2	0.0	1.1
21	diamict.	37.9	41.0	1.56	10.5	65	28	1.5	2.5	1.5	0.5	0.3
22	diamict.	39.5	35.0	1.43	14.0	64	27	0.5	5.9	1.0	0.0	0.5
23	diamict.	39.5	35.0	1.43	14.0	64	27	0.5	5.9	1.0	0.0	2.1
24	diamict.	36.2	40.5	1.97	12.0	63	31	1.2	3.4	2.6	0.5	1.0
25	diamict.	36.6	40.3	1.85	11.3	64	31	0.8	2.1	0.5	0.8	0.0
26	diamict.	37.3	40.5	1.93	9.7	65	31	0.8	2.6	0.0	0.8	0.8

Borehole r79ve46

DEPTH				TEXTURE	MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
1	diamict.	42.0	20.9	2.08	14.6							
2	diamict.	39.2	32.9	3.07	11.5							
3	diamict.	44.9	30.5	3.80	10.0							
4	diamict.	48.7	24.6	4.67	11.0							
5	diamict.	51.1	25.2	3.87	10.6							
6	diamict.	51.5	24.0	3.14	9.7							
8	diamict.	52.8	24.3	2.48	9.1							
10	diamict.	34.9	45.9	1.86	11.9							

12	diamict.	40.5	35.8	2.38	14.2
14	diamict.	28.7	42.4	1.23	10.8
17	diamict.	35.1	41.3	0.85	11.6
18	diamict.	32.3	42.0	1.29	10.7

Borehole r79ve47

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
1	diamict.	24.4	53.3	0.66	13.0							
2	diamict.	23.7	55.1	0.53	13.4							
3	diamict.	24.6	54.6	0.64	13.9							
4	diamict.	21.7	58.7	0.52	13.3							
5	diamict.	20.7	55.7	0.55	13.1							
6	diamict.	37.6	42.5	1.36	10.3							
7	diamict.	36.5	43.4	1.27	10.0							
8	diamict.	44.2	34.0	2.39	9.6							
9	diamict.	38.9	42.0	1.13	9.9							
10	diamict.	29.2	47.5	0.79	11.0							
11	diamict.	25.5	36.7	0.98	11.4							
12	diamict.	31.0	44.4	1.06	11.2							
13	diamict.	23.3	40.7	1.02	11.8							
18	diamict.	37.5	30.4	1.81	7.5							
19	diamict.	46.0	31.9	2.18	8.3							
20	diamict.	37.3	32.6	1.55	9.0							
21	diamict.	37.2	41.5	1.60	10.6							
22	diamict.	36.7	35.2	1.73	10.5							
23	diamict.	40.5	39.6	1.21	10.7							
24	diamict.	40.4	40.2	1.80	10.4							

Borehole r79ve48

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
1	diamict.	36.6	44.2	1.21	15.8							
2	diamict.	43.4	39.3	1.50	13.0							
3	diamict.	21.6	43.1	1.88	10.6							
12	diamict.	25.5	49.4	1.34								
13	diamict.	439.	38.5	1.13								
14	diamict.	39.2	37.0	1.62	19.8							

Borehole r79ve49

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
4	diamict.	35.7	36.0	1.30	12.1							
5	diamict.	35.8	35.5	1.31	12.4							
6	diamict.	33.5	37.8	1.04	12.5							
7	diamict.	33.6	37.6	1.24	12.3							
8	diamict.	33.7	33.9	1.17	12.1							
9	diamict.	43.9	28.9	1.17	12.5							
10	diamict.	55.4	23.1	1.74	9.4							
11	diamict.	54.7	27.1	1.94	9.6							
12	diamict.	48.4	25.5	1.35	9.9							
13	diamict.	53.6	25.3	1.75	9.6							
14	diamict.	44.2	33.3	1.90	13.1							
16	diamict.	36.0	39.2	1.35	10.2							
17	diamict.	37.2	39.2	1.35	10.2							
18	diamict.	38.3	38.4	1.45	10.8							

19	diamict.	37.0	35.8	1.65	11.3
20	diamict.	36.8	38.7	1.22	12.4
21	diamict.	39.3	38.1	1.46	12.7
22	diamict.	35.8	40.9	1.26	12.6
23	diamict.	34.8	39.3	1.47	12.3
24	diamict.	38.4	39.2	0.79	16.1
25	diamict.	34.8	41.8	1.33	12.3
26	diamict.	35.8	42.4	1.50	12.3
27	diamict.	35.8	42.6	1.48	12.5
28	diamict.	34.9	38.8	1.43	12.6
30	diamict.	37.0	37.9	1.43	12.5
31	diamict.	35.8	42.8	1.41	12.3
32	diamict.	36.2	40.5	1.45	13.3
33	diamict.	35.4	40.4	1.49	12.5
34	diamict.	35.1	40.2	1.33	12.5
35.	diamict.	36.9	39.9	1.24	11.9
36	diamict.	33.2	39.3	1.52	12.2
37	diamict.	38.6	39.3	1.52	12.2
38	diamict.	37.0	39.8	1.31	12.4
39	diamict.	37.8	39.8	1.87	11.7
40	diamict.	34.9	39.6	1.27	12.6
41	diamict.	36.7	39.9	1.47	12.3
42	diamict.	35.6	37.4	1.39	12.1
43	diamict.	33.4	42.5	1.14	13.4
44	diamict.	32.2	40.8	1.18	13.1
45	diamict.	38.6	35.6	2.23	10.7
46	diamict.	37.6	36.4	2.70	11.1
47	diamict.	33.7	37.0	1.88	13.5
48	diamict.	38.2	34.8	1.74	12.1

49	diamict.	38.2	41.2	1.75	12.1
50	diamict.	38.3	36.5	1.63	12.1
51	diamict.	42.8	36.4	1.81	11.2
52	diamict.	41.3	33.8	1.39	11.4

Borehole r80ve3

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	44.6	22.5	3.52	11.2	58	29	5.3	1.8	3.0	0.5	0.0
3	diamict.	43.2	22.9	3.06	10.7	50	34	3.8	3.4	5.3	2.0	0.0
4	diamict.	41.2	17.0	2.65	9.9	n/a						
5	diamict.	54.7	16.9	4.14	10.9	45	43	3.7	2.0	3.5	0.4	0.0
6	diamict.	47.0	25.0	3.26	11.2	40	42	3.7	5.5	5.5	0.9	0.0
9	diamict.	44.7	20.1	3.18	13.3	37	32	11.9	3.7	11.0	0.7	0.5.
10	diamict.	55.4	18.3	4.3	11.9							
11	diamict.	33.2	28.4	2.48	9.9	39	34	7.8	3.3	12.8	1.2	0.01
12	diamict.	37.8	31.5	1.76	10.0	47	42	3.6	5.6	4.2	0.0	0.0
13	ox.diamict.	34.1	35.3	1.61	7.9	57	32	4.2	2.7	1.8	0.9	0.0
14	ox. diamict.	30.1	32.1	1.08	6.6	47	43	3.6	2.9	2.2	0.0	0.7
15	diamict	40.1	29.5	2.75	7.9	45	36	2.5	7.0	5.0	0.3	0.0
16	diamict.	39.0	26.6	2.89	10.3	42	37	8.1	3.0	6.0	1.1	0.0
18	diamict.	31.4	31.9	1.48	9.3	52	19	13.1	4.8	2.3	1.5	0.0
20	diamict.	36.1	32.1	1.59	9.7	52	17	10.2	7.1	10.2	1.0	0.0
22	diamict.	32.9	31.0	1.79	9.8	39	32	8.1	4.3	10.7	0.0	0.7
24	diamict.	34.3	27.9	2.03	9.6	47	24	9.8	6.4	8.7	0.8	0.8
26	diamict.	38.3	31.2	1.62	9.5	45	23	13.3	7.1	8.0	1.5	1.0
28	diamict.	33.7	29.9	1.58	9.2	48	25	9.5	4.9	6.6	0.4	1.2

Borehole r80ve4

DEPTH		TEXTURE		MATRIX			COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
3	diamict.	41.9	46.1	1.14	5.6	55	28	0.8	0.8	4.7	0.8	0.0
4	diamict.	27.3	50.3	4.08	10.3	44	22	13.0	7.9	9.4	0.4	0.6
8	diamict.	29.8	37.4	1.44	11.9	45	21	7.2	10.8	10.3	0.0	1.3
9	diamict.	27.3	50.3	1.61	7.2	56	29	2.7	2.1	6.4	0.0	0.0
10	diamict.	47.0	31.4	3.33	10.7	56	24	8.0	2.8	6.8	0.5	0.5
11	diamict.	40.3	30.4	1.34	11.8	53	24	9.6	4 .8	7.0	0.0	0.0
16	diamict.	23.2	38.1	0.58	8.4	n/a						
18	diamict.	36.6	36.1	1.85	9.3	41	22	10.	7.0	12.6	0.9	3.1
19	diamict.	36.0	33.8	1.66	9.1	44	26	7.4	6.5	6.9	0.4	0.9
20	diamict.	37.1	36.4	1.62	9.0	43	26	9.7	9.3	8.4	0.0	2.0
21	diamict.	38.1	32.3	2.74	11.3	44	27	9.5	8.9	6.6	0.6	0.0
22	diamict.	27.5	35.9	1.61	11.2	42	25	8.2	6.9	8.5	.05	.02

Borehole r80ve5

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
3	diamict.	26.1	29.1	.79	6.7							
4	diamict.	34.8	16.6	1.49	6.5							
5	diamict.	30.5	21.1	1.6	8.0							
6	diamict.	32.5	23.5	1.49	7.9							
7	diamict.	27.1	38.5	1.06	6.9							
8	diamict.	21.1	38.5	0.77	6.9							

Borehole r80ve6

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	30.0	43.3	1.19	6.3							
3	diamict.	34.4	38.2	0.90	6.1							
4	diamict.	32.6	38.4	1.33	7.4							
5	diamict.	25.7	45.5	0.84	11.0							
13	diamict.	40.6	23..5	2.71	10.4							
14	diamict.	40.4	31.4	2.62	9.7							
15	diamict.	47.4	25.8	3.35	10.1							
16	diamict.	44.0	25.7	2.61	8.9							
18	diamict.	46.2	26.2	3.21	9.0							
20	diamict.	42.9	28.5	3.01	15.7							
21	diamict.	49.9	21.9	2.39	7.5							
22	diamict.	45.3	28.4	3.82	7.8							
26	diamict.	36.7	36.0	1.16	9.6							
27	diamict.	39.3	33.8	1.36	11.9							
28	diamict.	40.4	31.7	1.48	13.1							
29	diamict.	36.9	33.8	1.17	12.6							
30	diamict.	33.2	38.2	1.18	12.0							
31	diamict.	29.9	36.9	1.48	19.4							
33	diamict.	30.6	41.9	1.71	11.6							
34	diamict.	29.4	38.0	1.17	11.9							

Borehole r80ve7

DEPTH		TEXTURE			MATRIX	COARSE SAND MINERALOGY						
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	35.8	39.5	1.53	9.1	56	29	2.9	5.8	1.7	0.6	0.6
3	diamict.	32.7	38.5	1.31	8.4	54	32	4.0	2.6	2.6	00.6	0.8
4	diamict.	33.7	38.5	1.24	7.6	62	21	3.9	1.7	2.2	0.6	1.8
7	diamict.	36.2	34.7	1.11	10.5	43	30	8.9	3.0	10.1	0.0	0.2
8	diamict.	37.5	30.9	1.19	10.5	42	32	9.5	5.8	7.8	0.8	0.4
10	diamict.	38.4	31.2	1.54	11.3	50	22	7.1	3.8	10.4	0.0	0.3
11	diamict.	37.1	31.7	1.53	10.7	42	26	9.3	6.4	11.3	1.0	1.5
12	diamict.	40.4	30.9	2.16	10.1	43	22	9.8	6.5	12.5	0.0	0.5B

Borehole r80ve9

DEPTH		TEXTURE			MATRIX	COARSE SAND MINERALOGY						
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	32.4	40.2	1.33	14.0	55	26	1.7	6.1	3.9	0.0	0.0
3	diamict.	30.6	41.6	1.28	9.6	53	32	2.3	1.9	5.2	0.0	0.6
4	diamict.	33.0	31.8	1.19	11.5	55	25	2.4	5.4	6.0	2.3	1.8
5	diamict.	32.5	38.7	1.64	15.4	57	27	3.4	4.6	30.	0.0	1.5
6	diamict.	33.0	36.0	1.27	11.6	55	30	1.8	4.1	2.3	0.6	1.2
7	diamict.	28.2	33.8	2.29	13.8	n/a						

Borehole r80ve15

DEPTH		TEXTURE			MATRIX	COARSE SAND MINERALOGY						
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	36.2	35.4	1.56	10.5	66	21	1.7	3.4	2.3	0.0	0.3
3	diamict.	30.2	34.7	.87	8.3	56	31	0.9	3.5	2.6	0.9	0.9

4	diamict.	36.0	32.6	1.54	10.2	61	25	0.5	8.6	2.1	0.0	0.0
9	diamict.	38.5	30.0	1.56	14.2	70	16	1.7	4.1	1.2	0.4	1.2
11	diamict.	43.6	30.3	1.95	15.5	62	25	1.2	6.8	2.5	0.6	0.0
13	diamict.	41.1	28.4	2.57	14.1	56	31	3.8	6.0	0.6	0.3	0.0
14	diamict.	34.3	35.8	1.54	9.4	61	21	2.8	8.4	3.3	0.0	0.0
15	diamict.	34.9	33.7	1.54	9.5	56	25	0.5	8.9	2.1	0.0	1.0
16	diamict.	37.6	31.4	1.71	9.8	45	37	0.9	7.7	1.4	0.5	0.0

Borehole r80ve25

DEPTH		TEXTURE			MATRIX	COARSE SAND MINERALOGY						
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	37.7	19.2	1.46	7.2	52	33	3.2	0.5	6.9	0.5	0.03
3	diamict.	35.6	23.8	1.22	7.2	51	34	3.4	2.8	2.3	0.6	2.8
4	diamict.	35.6	23.4	1.49	6.7	56	29	2.6	3.7	4.2	0.0	1.6
6	diamict.	49.9	19.9	2.42	6.9	54	32	4.0	3.3	2.6	0.3	1.0
14	diamict.	34.7	27.4	1.64	9.9	52	20	10.8	5.4	5.9	0.0	3.2
16	diamict.	33.8	29.0	1.70	9.7	47	26	8.4	5.4	5.9	1.0	0.0
18	diamict.	33.7	25.6	1.68	9.6	48	28	10.9	1.9	7.6	0.0	0.0
19	diamict.	33.6	28.5	1.63	9.6	49	23	7.2	5.4	10.4	0.0	0.7

Borehole r80ve28

DEPTH		TEXTURE			MATRIX	COARSE SAND MINERALOGY						
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	32.9	26.7	1.26	11.9							
3	diamict.	37.1	26.8	1.64	11.3							
4	diamict.	39.5	27.2	1.79	11.8							
5	diamict.	36.6	25.5	1.37	12.3							
6	diamict.	37.2	28.4	1.81	8.49							

7	diamict.	38.1	30.0	1.50	10.6
8	diamict.	38.5	27.7	1.65	10.1
9	diamict.	44.3	28.8	1.92	9.4
10	diamict.	37.5	31.5	1.45	8.5
11	diamict.	37.1	27.4	1.5	10.6
12	diamict.	33.9	31.8	1.23	10.0
13	diamict.	37.4	30.8	.99	11.6
14	diamict.	33.6	31.5	1.15	12.4
15	diamict.	37.2	32.7	0.90	12.7
16	diamict.	34.3	35.2	0.95	12.7
17	diamict.	38.0	29.1	1.12	12.1
18	diamict.	38.3	33.9	1.04	9.6
19	diamict.	37.9	29.9	0.93	10.3
20	diamict.	34.3	32.9	0.85	11.6
22	diamict	34.5	40.6	1.37	12.2
23	diamict.	33.7	33.6	1.43	13.1
24	diamict.	29.3	38.6	1.53	10.7
25	diamict.	32.3	39.4	1.54	10.7
26	diamict.	45.1	24.2	2.15	6.7
27	diamict.	51.6	22.1	2.07	12.7
28	diamict.	44.6	25.0	1.93	9.8
29	diamict.	47.0	25.9	2.10	7.5
30	diamict.	43.6	27.2	1.93	10.4
31	diamict.	48.8	25.3	1.83	9.5
33	diamict.	50.3	26.6	2.37	10.3
34	diamict.	46.5	25.5	2.36	12.2
35	diamict.	48.1	23.9	2.12	6.2
37	diamict.	49.8	23.4	2.39	8.9

38	diamict.	48.0	23.3	2.11	7.2

Borehole r80ve30

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
2	diamict.	31.5	39.1	1.43	6.5	52	34	0.6	4.0	2.8	0.6	0.0
3	diamict.	21.7	48.2	0.74	5.6	61	21	5.4	5.4	2.7	0.0	0.0
4	diamict.	25.5	42.7	1.16	6.9	49	33	5.7	5.0	1.9	0.0	0.0
5	diamict.	29.3	43.3	1.49	6.9	48	23	6.6	5.4	6.0	0.0	0.6
6	diamict.	36.3	43.3	1.61	7.1	55	28	3.9	3.1	6.0	0.0	0.0
7	diamict.	28.4	45.8	1.07	6.9	58	31	1.4	1.4	1.7	0.0	4.0
8	diamict.	23.8	46.1	1.04	7.2	49	25	0.6	2.4	3.7	2.7	1.6
9	diamict.	30.4	37.8	1.39	7.2	56	23	0.6	3.2	3.2	0.0	0.6
10	diamict.	27.1	41.1	.096	6.7	61	24	4.5	3.8	1.5	0.7	0.0

Borehole r80ve38

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
3	diamict.	34.3	34.1	1.55	11.1	57	19	0.4	4.1	6.6	0.0	0.0
4	diamict.	34.0	38.6	1.36	15.9	61	30	0.6	4.0	5.6	0.0	0.0
5	diamict.	31.2	39.6	1.46	10.2	62	23	2.1	4.3	2.7	0.0	1.6
6	diamict.	33.9	33.6	1.47	10.3	61	23	1.5	3.9	2.4	1.0	0.0
7	diamict.	34.5	37.0	2.02	9.8	57	23	0.4	3.4	1.7	0.0	0.8

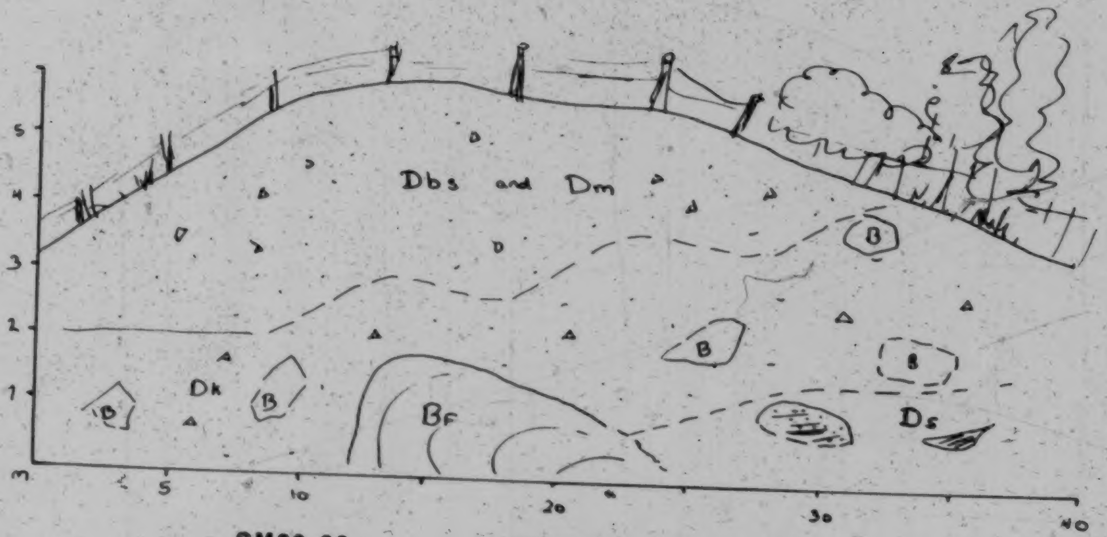
9	diamict.	38.4	33.7	1.33	7.9	53	31	4.6	2.0	5.6	0.0	0.0
10	diamict.	39.6	32.6	1.63	7.1	48	36	0.9	2.3	6.1	0.0	0.9
11	diamict.	39.5	31.9	1.59	6.1	50	34	4.0	1.5	4.0	0.0	0.0

Borehole r81ve17

DEPTH		TEXTURE			MATRIX		COARSE SAND MINERALOGY					
IN M.		SD%	CLAY%	C. SD%	CO3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS
1.5	diamict.	43.3	33.9	1.73	7.2							
3.0	diamict.	40.9	32.1	2.07	6.8							
4.5	diamict.	37.3	35.5	1.00	6.4							
6.0	diamict.	36.3	36.3	1.58	6.8							
7.5	diamict.	22.9	48.4	1.17	5.0							
9.1	diamict.	36.0	40.5	2.00	6.7							
10.6	diamict.	16.1	50.0	0.84	4.5							
12.1	diamict.	31.2	43.7	2.25	6.7							
13.7	diamict.	33.8	48.0	1.93	8.6							
15.2	diamict.	33.1	44.6	1.89	8.6							
16.7	diamict.	34.0	43.9	2.20	9.6							
22.8	diamict.	31.4	38.2	1.93	14.1							
24.3	diamict.	32.3	37.7	2.00	9.9							
25.9	diamict.	27.7	41.1	1.84	12.6							
27.4	diamict.	36.6	44.1	1.97	12.9							
32.0	diamict.	36.6	41.5	2.35	13.8							
33.5	diamict.	36.4	36.0	2.24	13.7							
35.0	diamict.	34.9	44.3	1.86	14.2							
36.5	diamict.	28.3	40.6	1.72	14.9							
38.1	diamict.	28.4	45.7	1.84	14.6							
39.6	diamict.	27.6	39.5	1.81	13.9							

44.1	ox.diamict.	32.5	40.6	1.28	11.5
45.7	ox.diamict.	48.2	29.7	2.29	10.7
47.2	ox.diamict.	49.4	26.3	2.75	10.9
47.7	ox.diamict.	51.3	30.4	2.55	10.1
50.2	ox.diamict.	28.0	41.6	2.13	4.7
51.8	ox.diamict.	30.7	33.8	0.48	4.3
54.8	diamict.	31.0	32.6	0.95	7.7
56.3	diamict.	35.7	41.9	1.98	11.7
57.9	diamict.	32.4	36.0	2.18	11.2
50.9	diamict.	30.9	54.7	2.16	11.7
60.9	diamict.	33.1	25.5	1.43	13.4

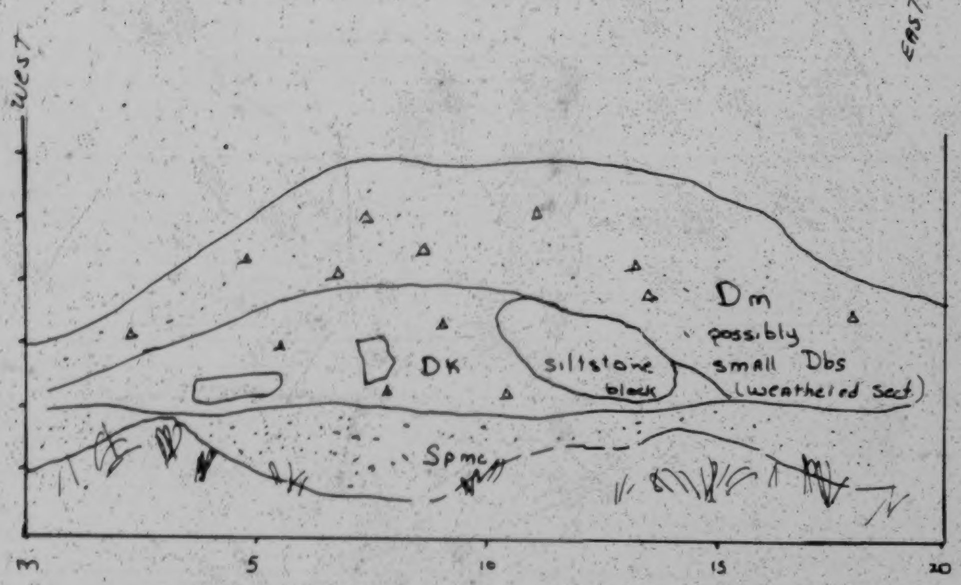
APPENDIX 4. CROSS SECTIONS DESCRIPTION


5
4
3
2
1
m
5
10
20
30
40
Dbs and Dm
Dk
B
Bf
Ds

CM82-99 **STAGNANT ICE MORAINE**

LOCATION: TWP 57, RGE 5 W 4, SEC. 21, LSD NW 14

Dm: massive diamicton
Dk: massive diamicton with inclusions
Dbs: banded diamicton and sand
Ds: massive diamicton with sand lenses
Bf: disturbed bedrock


WEST
EAST
Dm
possibly small Dbs (weathered sect.)
siltstone block
DK
Spmc
m
5
10
15
20

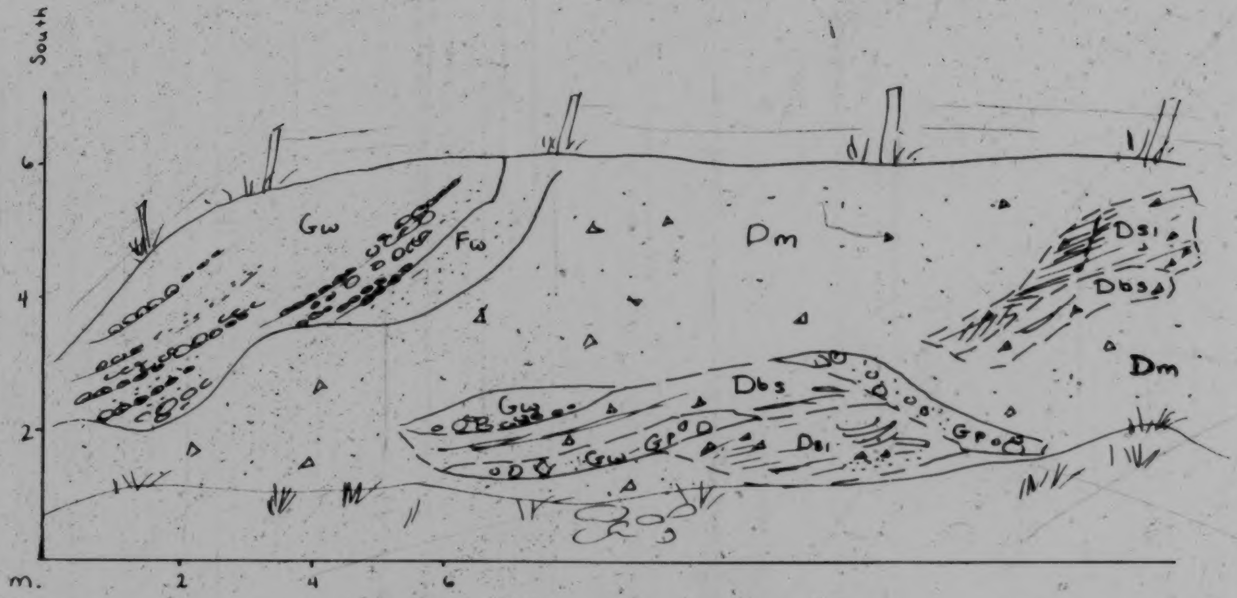
CM82-253 **STAGNANT ICE MORAINE**

LOCATION: UTM N: 80.9, UTM E: 47.6

Dm: massive diamicton

Dk: massive diamicton with inclusions

Spmc: sand, m-c gr., unsorted, poorly stratified


South
6
4
2
m.
2
4
6
Gw
Fw
Dm
Dsi
Dbsd
Dm
Gw
Dbs
Gp
Gw
Gp
Dsi
Gp

CM 83-103 **STAGNANT ICE MORAINE**

LOCATION TWP 47, RGE 2 W 4, SEC 15, LSD NE 1

Dm: massive diamicton

Dsi: interbedded diamicton, sand and silt

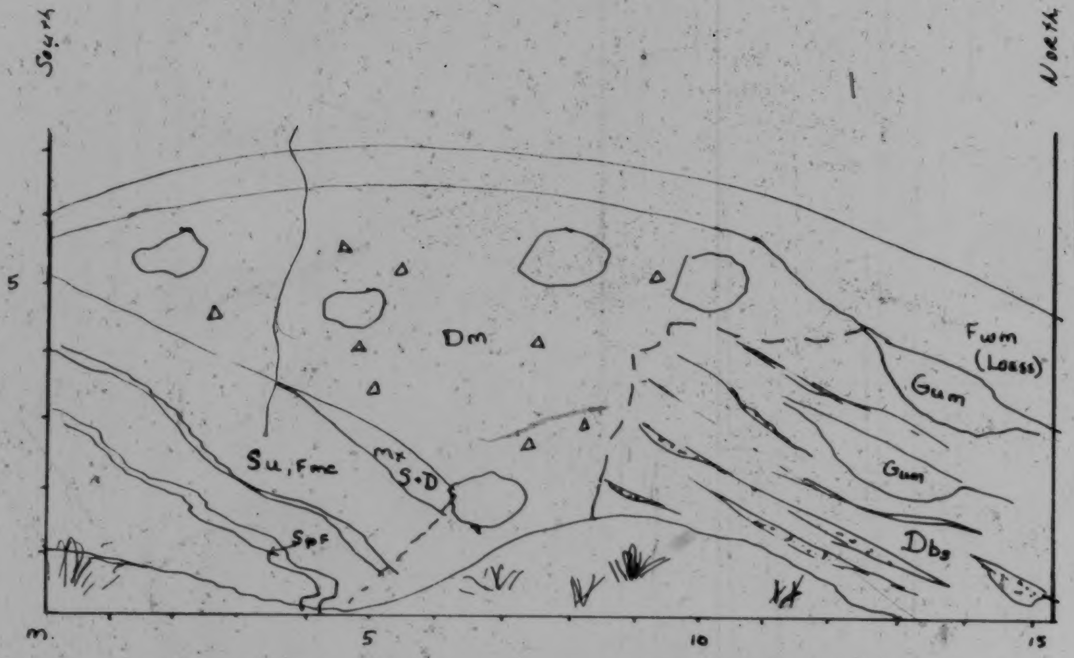
Dbs: banded diamicton and silty sand

Gp: poorly sorted gravel

Gw: well sorted gravel

Fw: well sorted fine sand and silt

This section is located on the margin of a meltwater channel.


South
North
5
m
5
10
15
Dm
Su, Fmc
Mx S.D
Spf
Fwm (Loess)
Gum
Gum
Dbs

CM84-5 **STAGNANT ICE MORAINE**

LOCATION: TWP 50, RGE 2 W 4, SEC. 30, LSD SC 3

Dm: massive diamicton

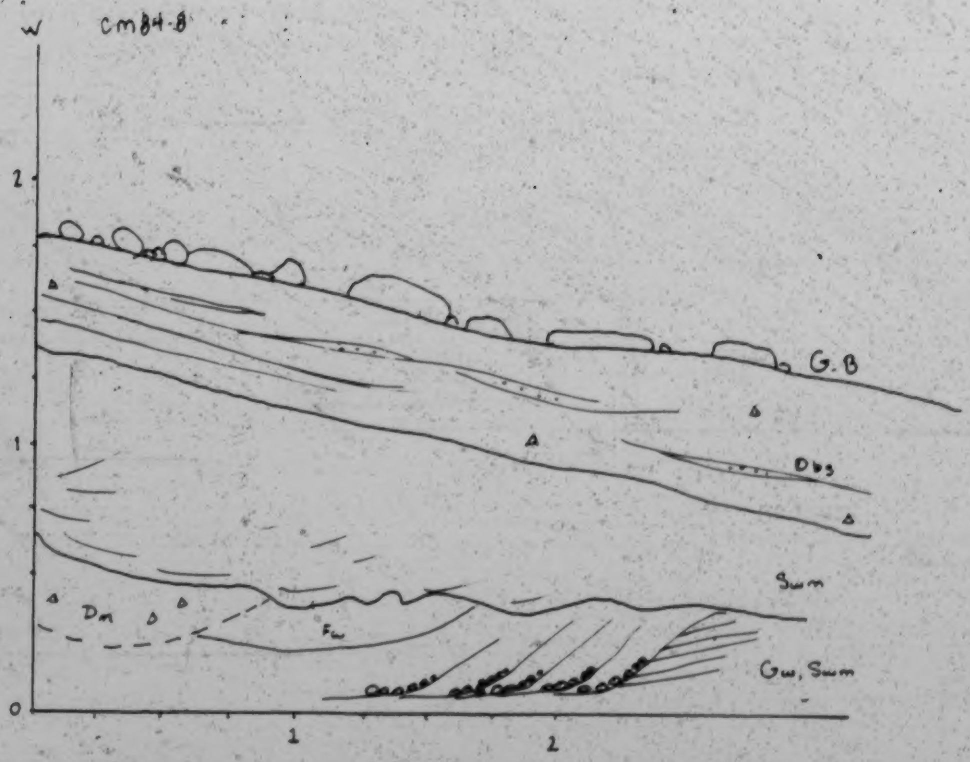
Dbs: banded diamicton and silty sand

Fwm: fine gr. sd and silt, well sorted, massive

Suf: sand, m-c gr., unsorted,folded(poorly stratified)

Spf: sand . poorly sorted, folded

Gum: gravel, unsorted , unstratified


W
CM84-8
2
1
0
G.B
Dbs
Swm
Dm
Fw
Gw, Swm
1
2

CM84-8 **STAGNANT ICE MORAINE**

LOCATION: TWP 53, RGE 1 W 4, SEC 13, LSD NE 15

G-B: Boulder lag
Dbs: banded diamicton and silty sand
Swm:well sorted medium gr. sand
Dm: massive diamicton
Fw: well sorted silt and fine sand
Gw: well sorted gravel

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THE UNIVERSITY OF ALBERTA

The Quaternary Geology of the Vermilion-East area, Alberta

by C. M. Mougeot ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

SPRING 1991

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "The Quaternary Geology of the Vermilion-East Area, Alberta" submitted by C. M. Mougeot, in partial fulfillment of the requirements for the degree of Master of Science.

Dr. N.W. Rutter
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Date Apr 13 1991

ABSTRACT

The Vermilion-East area is located at the core of heavy hydrocarbon development in east central Alberta and as a result the requirement for applied information related to Quaternary geology prompted a mapping survey and stratigraphic investigation.

Thick sequences of Quaternary deposits are preserved in buried valleys which show a lithostratigraphic framework composed of 1. a preglacial stratified unit, 2. six diamicton units associated with 4 major glacial events and 3. three stratified units related to the corresponding interglacial intervals. Based on lithostratigraphic correlations, the oldest glacial event is probably pre-Wisconsinan followed by glaciations ranging from the early Wisconsinan to late Wisconsinan. The last glacier retreated in a complex sequence involving two main ice bodies or lobes. Each lobe affected the morphology of the map area where it is expressed either by the deposition of moraines, glaciofluvial and ice contact deposits or by the formation of meltwater channels.

The surface geology mapping conducted in the Vermilion-east area resulted in the reconstruction of this deglaciation sequence and the production of a terrain model which includes the facies description of selected sections through four moraine types: stagnant ice moraine, fluted moraine, rubble moraine and thrusted moraine. All these moraines have been traditionally described as containing massive diamicton. The composite model for each landform provides a detailed description of the sediments occurring within the landform augmented by comments on the predictability and variation of their physical properties.

ACKNOWLEDGMENTS

I wish to thank the Alberta Geological Survey and Environmental Research and Engineering Department of the Alberta Research Council for their support: all field data, air photos, basemaps, the assistance of many helpful summer students, most of the laboratory analysis and of the computer processing of data were provided during my employment by the Alberta Research Council. They allowed for flexibility of my working hours so that I could attend graduate classes and various field trips and also provided an atmosphere conducive to research where discussions with Quaternarists such as Mark Fenton, Steve Moran, Laurence Andriashek, Irena Shetsen and others fostered an understanding and integration of the various aspects of Quaternary geology.

I am particularly grateful to Dr. Mark Fenton for introducing me to Quaternary geology in the Prairies and for his patience and support during this project. Mark, in addition to being an excellent geologist and teacher, opened vista for me through his involvement in science at an international level. This thesis has benefited from discussions and field trips in which I participated thanks to him.

I also owe many thanks to Dr. N. Rutter who stood by me through the many interruptions during the writing of the thesis-including a move to the Yukon, a busy mapping schedule, the arrival of two kids- and who provided many constructive insights and recommendations. There is much talk these days about fostering post-secondary education for women and access to non-traditional employment and the University of Alberta Graduate Studies Faculty and the Department of Geology have been very flexible and cooperative. The Quaternary Research Group (graduate students) of the Geology Department, more specifically Norm Catto and John Kulig, were also very helpful either through their discussions in the field or by commenting on the first draft of the thesis.

The committee's recommendations were an important contribution to the thesis and I thank them for their careful and thoughtful comments.

The final corrections and administrative formalities required for the completion of the thesis would have been a logistical challenge without the help of my good friend, Judy Larmour, who generously babysat my youngest son during the week of the thesis defense.

And last but not least, I want to thank my husband Steve for all the hours he spent editing my English, which was no minor task as it is a second language for me, for the hours he babysat while I worked at my computer and for his unfailing support through all my endeavours. Without his encouragement and sense of humor, I might never have mustered enough energy to complete this thesis.

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CHAPTER ONE INTRODUCTION

1.1 GENERAL STATEMENT

The Vermilion study area is located west of the Alberta-Saskatchewan border and consists of the east half of the N.T.S. map sheet 73E (Figure 1). The town of Lloydminster is located in the southeastern part of this area and is a major service center for the oil and gas industry. This thesis is the result of a surface geology mapping survey and drilling program funded by the Alberta Research Council and initiated in response to increased activity due to hydrocarbon development in the Lloydminster area. Information about the Quaternary geology was required for groundwater potential, soils, possible sites for waste disposal, aggregate sources and general planning of land uses.

Also, of geological interest is the fact that this area lies well behind the southern limits of the last glaciation and thick Quaternary deposits are preserved in the buried valleys and provide records of multiple glaciations over central Alberta.

Furthermore the geomorphology of this area is composed of a great variety of glacial landforms. During the survey, some of these landforms were studied not only as landmarks for glacial positions but with a sedimentological focus on lithofacies types. Glacial deposits or moraines are often described on surface geology maps as containing till plus minor sand, gravel and lacustrine deposits. This blanket statement says very little about the distribution, range and variety of sediments present within various glacial landforms.

In this thesis, sections through selected glacial landforms were described with a facies scheme developed in the field. By documenting the internal variations of sediment types within glacial landforms, the author designed landform models for selected moraine types. The model complements the information supplied by a traditional mapping project and presents a more detailed description of the landform composition and of its expected variability and geotechnical behavior.

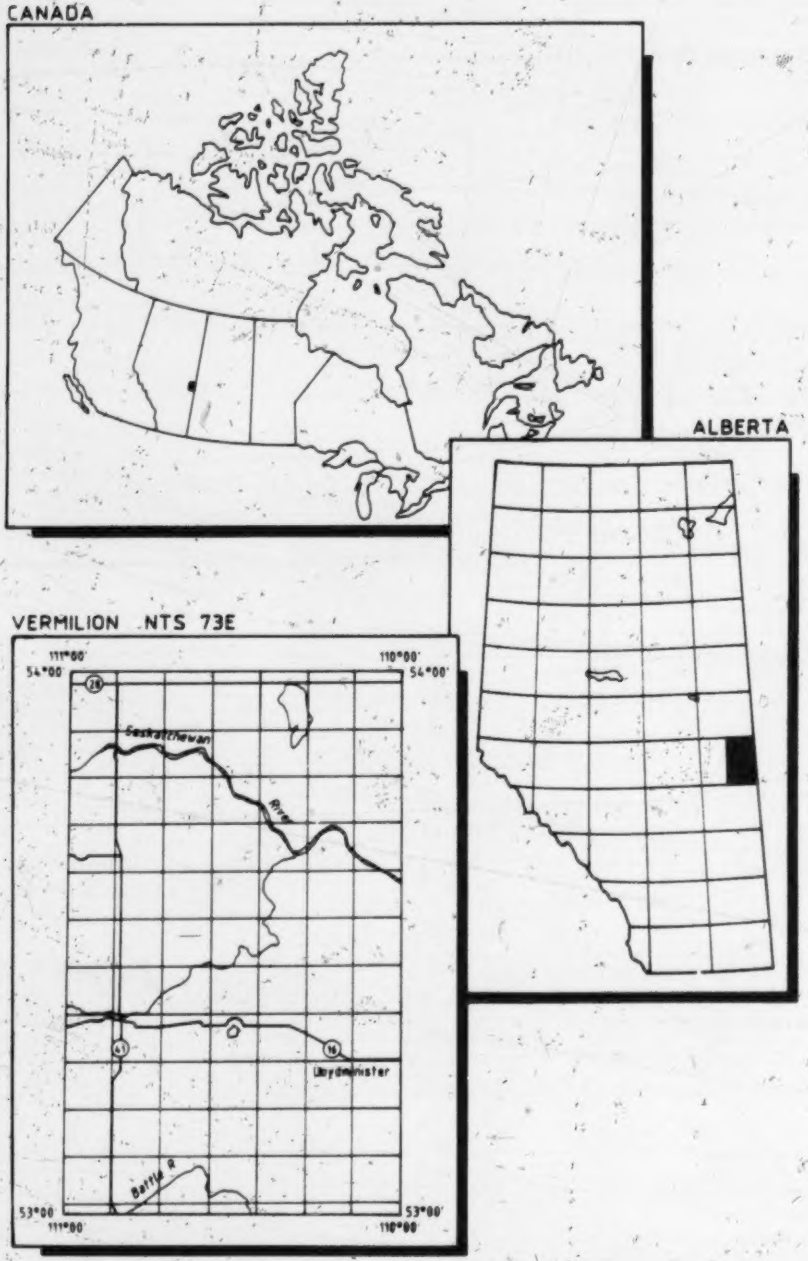

CANADA
ALBERTA
VERMILION NTS 73E
111°00'
110°00'
54°00'
54°00'
28
Saskatchewan
River
41
16
Lloydminster
Battle R
53°00'
53°00'
111°00'
110°00'

Figure 1: Location Map of Study Area

1.2 OBJECTIVES

The main objectives of this thesis are;

1) to model selected glacial landforms using a facies scheme and to use these models as tools for planning land uses,

2) to establish general Quaternary stratigraphy using subsurface data, and

3) to reconstruct the deglaciation sequence for the area.

To achieve the first objective, lithofacies types were compiled from exposure descriptions and linked into groups or assemblages to characterize landforms composed mainly of diamictons. This approach provides both the descriptive information required to define the lithological composition, range and distribution of sediments present in a landform and an understanding of the depositional environment of these deposits. A landform model summarizes the findings for each selected glacial landform.

Glacial stratigraphic units and their mineralogical and textural properties were defined from subsurface samples in a similar fashion to that of Andriashek (1984). The stratigraphic information and the surficial geology map were used to reconstruct the deglaciation history of the area.

1.3 CLIMATE

The climate of this area is continental with dry, hot summers and cold winters, with low precipitation and extreme temperature variations between summer and winter. The mean temperature for January is -17° C and for July is 17°C. Average annual precipitation is 41 cm with most of the precipitation occurring from June to August.

1.4 VEGETATION

The Vermilion-East area is part of the plains-parkland transition zone of east-central Alberta (Rowe, 1972; Hosie, 1980) but is mainly deforested and intensively farmed. Trembling Aspen, Balsam Poplar and occasionally White Birch are still found in natural stands. In the Frog Lake area north of the North Saskatchewan River, little clearing has taken place, and mixed forest with conifers such as White Spruce and Balsam Fir grow on better drained sites with Black Spruce and Tamarack found in poorly drained areas.

Natural communities of grasses occur in the area and include blue grasses, wheat grasses and brome grasses which may be used as natural pasture. Wild barley or foxtail barley is commonly found on slightly saline soils.

1.5 SOILS

The main soil groups present in the east half of the Vermilion map sheet are the Gray and Dark Gray Luvisolic, Dark Gray and Black Chernozemic soils.

The Gray Luvisolic soils are found mostly north of the North Saskatchewan River in the area around Frog Lake. Dark Grey Chernozemic and Luvisolic soils are found in a triangle that runs roughly from Elk Point to Raft Lake to the north of the North Saskatchewan River. Regosols are found on the recent alluvial parent material in the Vermilion, North Saskatchewan and Battle River drainage areas. Black Chernozemic soils cover the southern half of the area. The Vermilion map sheet is located directly north of the boundary between the Black and Brown Chernozems and transitionary soils may be found on the southernmost part of the map sheet. Solonetzic soils usually sit in poorly drained areas, mostly old basins and depressions around Vanesti and Kenilworth Lake (Wyatt and Newton, 1944).

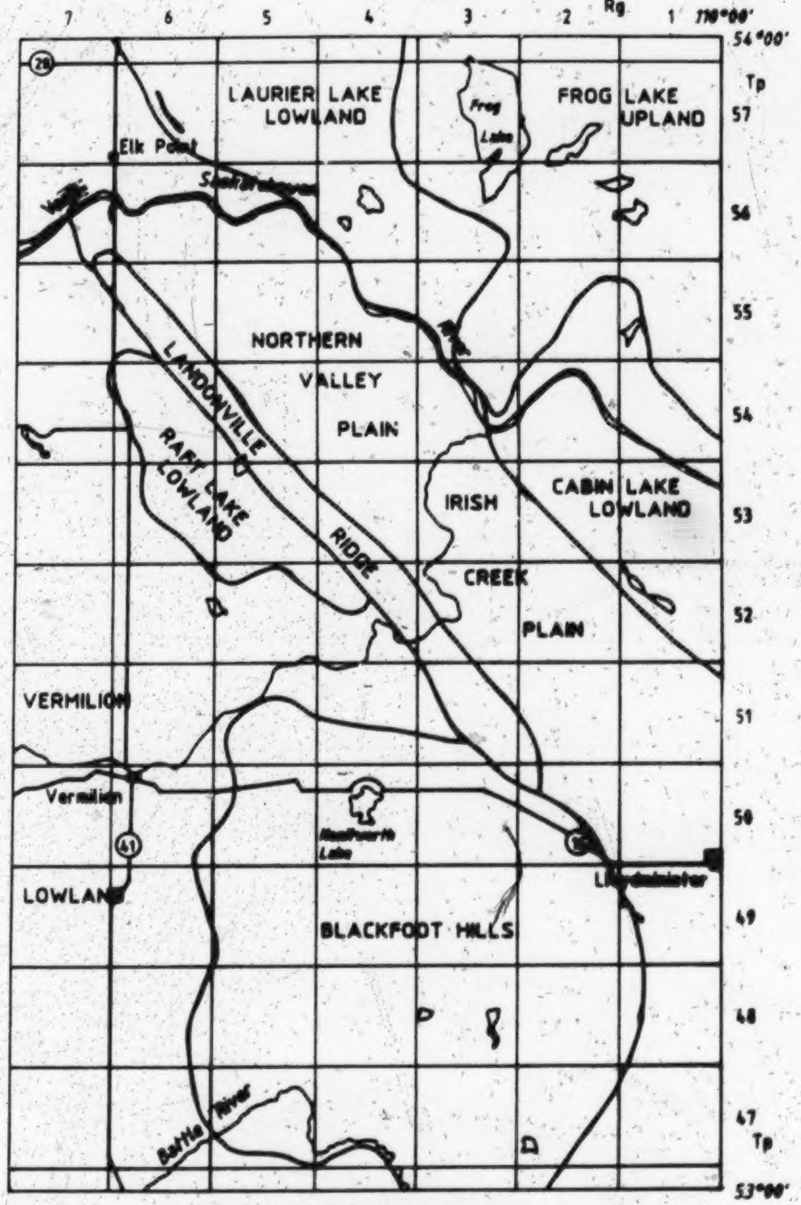
CHAPTER TWO GENERAL GEOLOGY

2.1 PHYSIOGRAPHY

The Vermilion-east area is part of the east-central Alberta Plains (Pettapiece, 1987) and is a low relief, undulating to hummocky plain with higher relief areas in the southeast and northeast corners. It is drained northerly by the North Saskatchewan, Vermilion and Battle Rivers (Figure 2). To facilitate further discussion, the survey area is divided in this thesis into 7 local physiographic units based on elevation, relief and general morphology. These include the Frog Lake Upland, Laurier Lake Lowland, Irish Creek Plain, Landonville Ridge, Raft Lake Lowland, Vermilion Lowland and Blackfoot Hills (Figure 2).

The Frog Lake Upland is located on the north side of the North Saskatchewan River (Figure 2) and has hummocky topography with an average relief of 3 to 10 metres. Average elevation is 650 metres, with a maximum elevation of 685 metres. Quaternary sediments are as thick as 90 metres and their thickness generally decreases towards the south. A small field of glacial flutes oriented southwest is present west of Frog Lake. This area contains many lakes including Frog Lake (township 57, range 3) (Figure 2), Long Lake (township 56, range 1), Rock Island Lake (township 56, range 1) and Fishing Lake (township 57, range 2) (Figure 3 in back pocket).

The southern boundary of the Frog Lake Highland is bordered by a steep scarp approximately parallel to the North Saskatchewan River (Figure 2). This marks the northern boundary of the Laurier Lake physiographic unit. The Laurier Lake Lowland (Figure 2) is a band of hummocky to rolling terrain north of the North Saskatchewan River valley. Topography is subdued (1 to 3 metres) with relief in the range of 3 to 10 metres. Average elevation is 585 metres with a maximum elevation of 646 metres. Glacial sediment thickness is generally less than 15 metres.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LAURIER LAKE LOWLAND
FROG LAKE UPLAND
Frog Lake
Elk Point
Saskatchewan
NORTHERN VALLEY PLAIN
LANDONVILLE RIDGE
RAFT LAKE LOWLAND
IRISH CREEK PLAIN
CABIN LAKE LOWLAND
VERMILION LOWLAND
Vermilion
41
Lloydminster
BLACKFOOT HILLS
Battle River

Figure 2: PHYSIOGRAPHIC UNITS

The Irish Creek Plain (Figure 2) is subdivided into the Northern Valley Plain and the Cabin Lake Lowlands (Figure 2). The Northern Valley Plain (Figure 2) is an undulating plain with an average elevation ranging from 655 metres to 640 metres. Average relief is 2 metres and maximum relief is 15 metres. The surface is generally fluted with a southeast orientation. South of the Vermilion River (Figure 2), the fluted terrain merges into a low relief hummocky terrain. Glacial sediment thickness decreases southward from 70 to 15 metres. Meltwater channels are found in areas such as Moosehills Lake (twp. 57, rge. 6), St- Yves Lake (twp. 52, rge. 2), Big Gully Creek (twp. 51, rge. 1), Pasatchaw Lakes (twp. 52, rge. 1-2), Devonia Lake (twp. 49, rge. 1) and Blackfoot Creek (twp. 47-50, rge. 1-2), (Figure 3)

The Cabin Lake Lowland (Figure 2) located south of the North Saskatchewan River is a 8 kilometre band of hilly terrain which extends from Cabin Lake to the Saskatchewan boundary. Average elevation is 610 metres with maximum elevation of 655 metres. This unit is also dissected by meltwater channels, with high relief knobby to hilly topography between the channels. Quaternary deposits range in thickness from 3 to 10 metres and the area is drained through Leighton Creek (twp. 53, rge. 1), (Figure 3) and the North Saskatchewan River.

The Landonville Ridge (Figure 2) is a 35 metre high, 2 kilometre wide, 60 kilometre long ridge with a strike of S40E. It originates south of the North Saskatchewan River (Figure 2), has a base elevation of 645 metres and is approximately 45 metres thick. The ridge top is nearly flat and covered with low relief hummocky terrain This physiographic unit is an important marker which separates the map area in two general areas: thick Quaternary deposit sequences (which rest mostly on the Lea Park Formation) in the northeast, and to the southwest, discontinuous and thinner Quaternary deposits which rest on the Belly River Formation.

The Raft Lake area (Figure 2) is an 8 kilometre wide band of very hummocky terrain located directly west of and parallel to the Landonville Ridge (Figure 2). Base elevation is 635 metres and average relief is 15 metres, with a maximum relief of 25 metres. Topography is hummocky with poorly defined ridges which are weakly oriented northwest-southeast. Glacial sediment thickness varies from 8 to 35 metres.

The Vermilion Lowland (Figure 2) is located in the western part of the map area and has an average elevation of 645 metres. The terrain is hummocky with a relief varying from 3 to 10 metres with isolated knobs up to 40 metres. Glacial sediments have an average thickness of 8 metres.

The Blackfoot Hills (Figure 2) are composed mostly of sandstone and siltstone of the Belly River Formation and they rise 75 to 90 metres above prairie level. Maximum elevation is 777 metres and minimum elevation is 625 metres around Baker Lake (Figure 3).

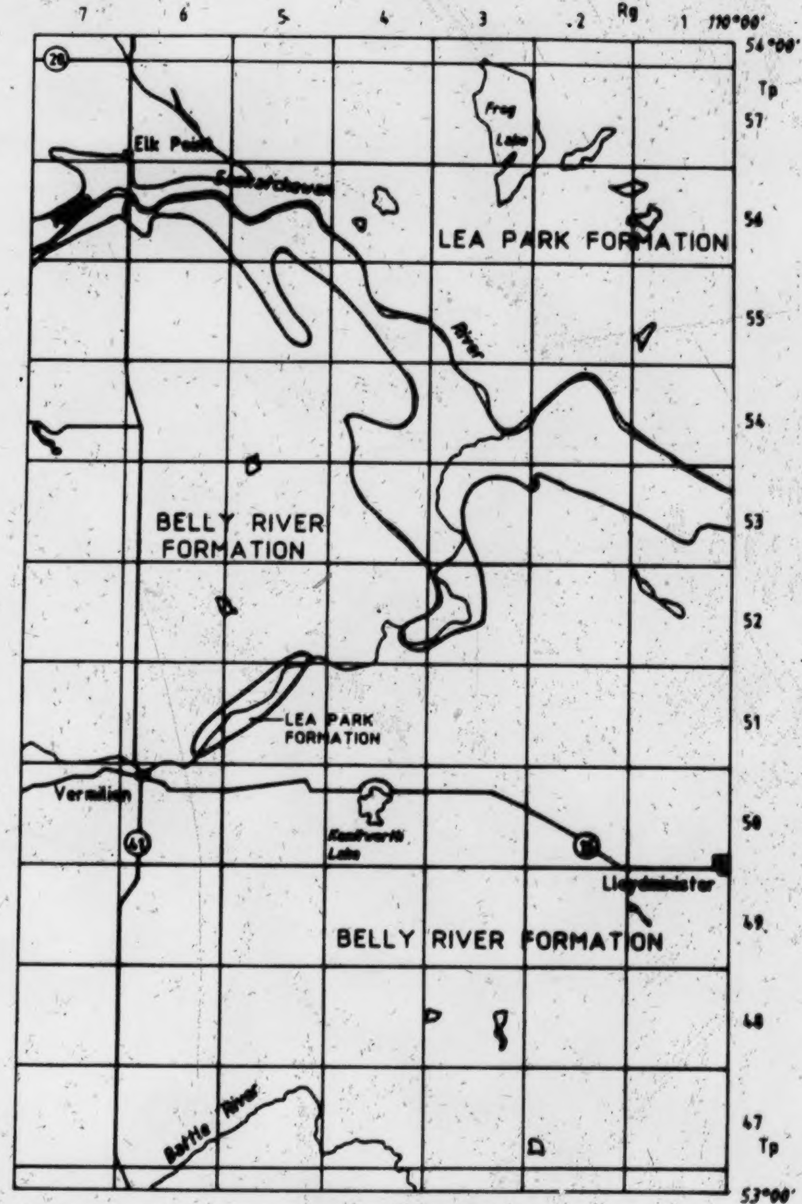
2.2 BEDROCK GEOLOGY

Two Cretaceous formations underlie the map area; the Lea Park and Belly River Formations (Figure 4). The Lea Park Formation is present in the North Saskatchewan and Vermilion valleys in the northeast. The Belly River Formation underlies the remainder of the Vermilion East map area.

Bedrock geology was first described by Dawson(1883) and Allan (1917). Later, Shaw and Harding (1949), Nichols and Wyman (1969), and McLean (1971), Currie and Zacharko (1975) completed detailed studies of these Cretaceous Formations. McKellar (1977) collected and described micro and macro-fossils of the Lea Park Formation.

2.2.1 LEA PARK FORMATION

The Lea Park Formation is a westward-thinning wedge of marine silty shale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54
53
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51
50
49
48
47
Tp
53°00'
28
Elk Point
Saskatchewan
River
Frog Lake
LEA PARK FORMATION
BELLY RIVER FORMATION
LEA PARK FORMATION
Vermilion
41
Kenilworth Lake
16
Lloydminster
BELLY RIVER FORMATION
Battle River

Figure 4: BEDROCK GEOLOGY
from Green 1972

with occasional ironstone concretionary beds, sandy shale and thin grayish bentonite beds. The shale is dark grey to brownish gray and appears massive to laminated. Stratification is almost horizontal with a very low dip to the southwest and the upper contact is conformable. It is believed that these shales were deposited "in quiet water of a neritic middle shelf environment during the early to middle part of the late Campanian" (Mckellar, 1977).

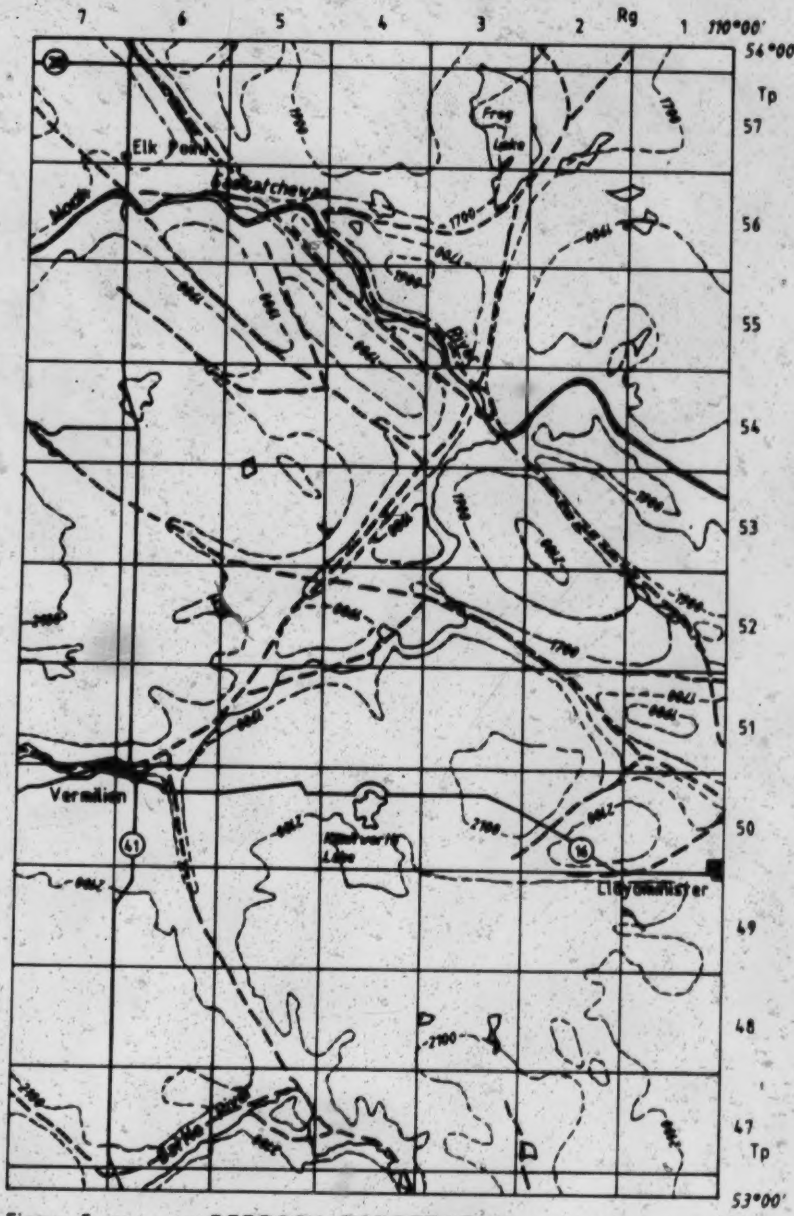
The type section is located in Lea Park, at the mouth of the Vermilion River, where 25 metres of the Upper Lea Park Formation are exposed. In exposures, it is identified by its very dark and uniform gray color, absence of any coarse-grain material and presence of ironstone and/or bentonite beds. The total thickness of the Lea Park Formation varies between 140 to 250 metres.

2.2.2 BELLY RIVER FORMATION

The Upper Cretaceous Belly River Formation overlies the Lea Park and consists of alternating beds of gray to brownish gray sandy siltstone and shales and massive yellowish gray sandstone. Thin interbeds of carbonaceous shale and coal are common in the sandstone. Thin calcareous and ironstone concretion beds are scattered throughout in the finer-grained beds. Bedding is generally horizontal with a slight dip towards the northeast. Belly River rocks represent a transition from a marine to continental depositional environment, as deltaic sands and offshore silt interfinger with the Lea Park marine shales. Currie and Zarcharko (1975) have defined the lower Belly River as intertonguing marine shale and deltaic sandstone and the upper Belly River as non-marine shale, coal, siltstone and sandstone. Average thickness is 30 metres, wedging out toward the northeast. Contact between the Belly River and Lea Park Formations is gradational and is believed to dip to the southwest with a slope of 4 m. per km.

2.3 BEDROCK TOPOGRAPHY

The bedrock topography map (Figure 5) was modified from Carlson and Currie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53°00'
Elk Point
North Saskatchewan River
Frog Lake
Vermilion
41
16
Lloydminster
Battle River
1700
1900
2000
2100

Figure 5: BEDROCK TOPOGRAPHY

modified from Carlston and Currie 1973

— — — Thalwegs

- - - - - Bedrock elevation in metres

(1975) where new subsurface data justified the changes. Glacially disturbed material and irregular density of borehole information allow only a general contouring of the bedrock topography. The bedrock topography map shows a dissected plain with plateau surfaces gently sloping northeast, from 675 metres in the southwest to 585 metres in the northeast.

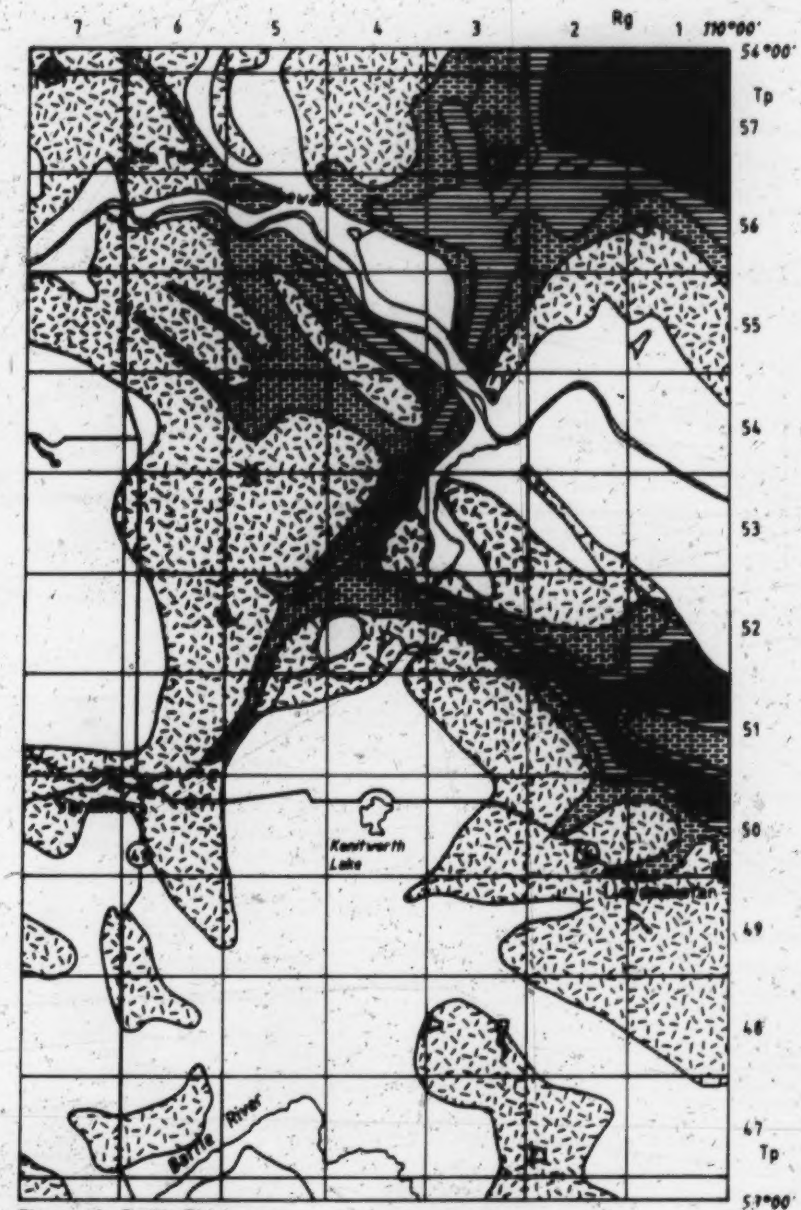
The main buried preglacial valley is the Vermilion paleo-valley (Stalker, 1961). It enters the map area just south of Vermilion and then trends northeast toward Frog Lake (Figure 5). The Vermilion valley is broad (4 to 5 kilometres) with a low gradient of 1.7 m per km, (Andriashek, 1985) and varies in depth from 30 metres from the surface in the Vermilion area and up to 120 metres at Frog Lake.

An additional deep buried valley is located directly north of Lloydminster and trends towards the southeast. It is present in this map area for only a short distance (Figure 5) and is approximately 120 metres below present surface. It is likely that this channel is a tributary to a major pre-glacial channel.

From the bedrock and surface topography maps, a drift thickness map can be plotted (Figure 6) and the following generalizations are possible: 1) drift thickness is greatest in the northern and eastern portion of the map, east of the Landonville ridge, and thickest in preglacial valleys; 2) surface expression of this thick drift is dominated by high relief stagnant ice moraine and fluted moraine; and 3) drift is thin west of the Landonville Ridge, and is thinnest in the Blackfoot Hills and around the Battle River. The surface expression of these thin drift areas is mainly thrusted and rubble moraine, low relief stagnant ice moraine and low relief undifferentiated moraine.

2.4 REVIEW OF PREVIOUS QUATERNARY GEOLOGY STUDIES

The Quaternary geology of eastern Alberta was briefly described by Tyrrell (1887), Rutherford (1941), Warren (1954). A soil survey was conducted in the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Tp
53°00'
Kenilworth Lake
Battle River

Figure 6: Drift Thickness

Thickness of drift in metres

☐ less than 15

▨ 15 to 45

▤ 45 to 80

☰ 80 to 110

■ more than 110

from Carlson and Currie 1973

1940's (Wyatt and Newton, 1944) and provides general information about the parent material of the soils. Gravenor and Kupsch (1959) described the stagnant ice moraine landforms of the area directly west of this survey and proposed depositional models which are still in use for those landforms. Hydrogeology reports (Farvolden, 1963; Lebreton, 1963; Currie and Zacharko, 1975) and an aggregate resource report published by the Alberta Research Council also provide general information about the geology and glacial deposits of the map area. Stalker (1963, 1976, 1977) has worked intensively in southern Alberta and has produced a variety of information both on the surface geology and stratigraphy south of the study area. Christiansen (1968) and Whitaker and Christiansen (1972) (Table 1) have worked out a general stratigraphy in Saskatchewan and these stratigraphic studies can be extended in eastern Alberta and provide a base for correlations

Ellmwood (1961) was the first to map the Quaternary geology of this area and to describe the glacial deposits in detail (e.g. ground moraine, hummocky moraine, streamlined features and crevasse fillings). He recognizes the presence of bedrock disturbed by glacial processes and identifies only one stratigraphic glacial unit. A regional mapping project of central and southern Alberta was recently completed by Shetsen (1990) and includes the study area. Jones (1981) conducted field investigations related to the fluting field that extends from Lac La Biche to the Lloydminster area.

Both Fenton (1984) and Klassen (1989) provide a concise and complete summary of stratigraphic investigations in Western Canada. Klassen (1989) presents the general Quaternary geological and stratigraphic framework of the Canadian Prairies and briefly discusses some of the unresolved issues such as the maximum ice limits of the late Wisconsinan glaciers, the number of nonglacial periods that occurred during the Wisconsinan and the correlation between Cordilleran ice advances from the Canadian Rockies and the Laurentide ice advances

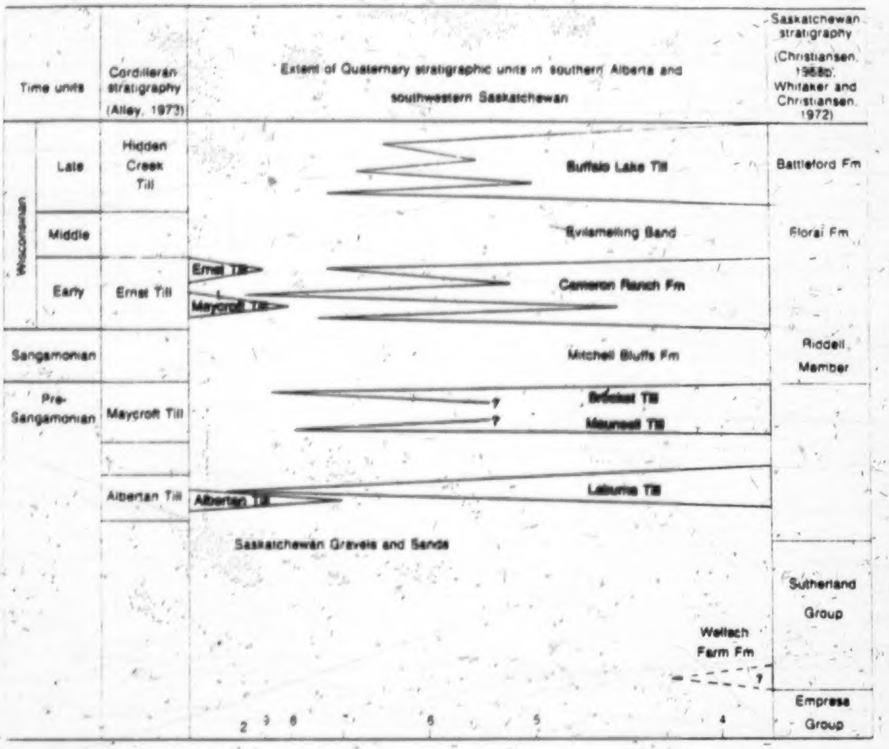

Time units
Cordilleran stratigraphy (Alley, 1973)
Extent of Quaternary stratigraphic units in southern Alberta and southwestern Saskatchewan
Saskatchewan stratigraphy (Christiansen, 1968b; Whitaker and Christiansen, 1972)
Wisconsinan
Late
Hidden Creek Till
Buffalo Lake Till
Battleford Fm
Middle
Bvismelling Band
Floral Fm
Early
Ernst Till
Ernst Till
Maycroft Till
Cameron Ranch Fm
Sangamonian
Mitchell Bluffs Fm
Riddell Member
Pre-Sangamonian
Maycroft Till
?
?
Brocket Till
Maunsell Till
Albertan Till
Albertan Till
Labuma Till
Saskatchewan Gravels and Sands
Sutherland Group
Wellsch Farm Fm
?
Empress Group
2
3
8
6
5
4

Table 1. Quaternary Stratigraphy of the Canadian Prairies (after Klassen, 1989).

from an eastern source (Laurentian continental ice). Klassen's summary of the Quaternary stratigraphy (Table 1) generally agrees with the stratigraphic sequence suggested by Fenton (1984) (Table 2) summarized below.

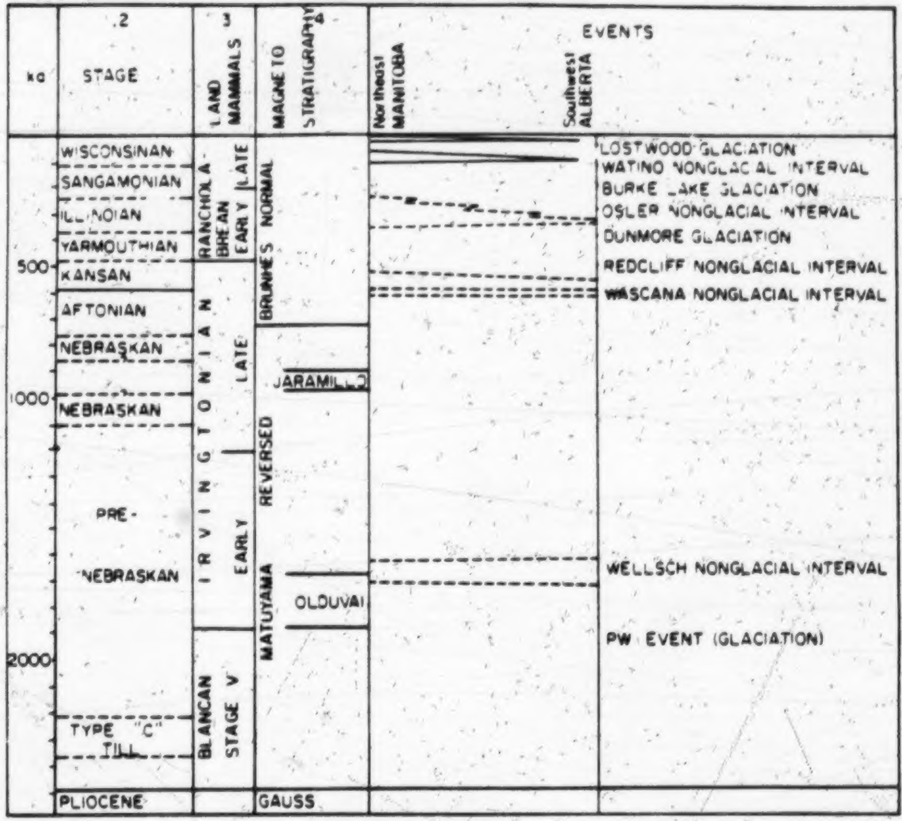
Fenton proposes 9 major Pleistocene event units with chronological control (Table 2) based on vertebrate fossils, paleomagnetic interpretations and tephra dates. Early Pleistocene events include the Pre-Wellsch glaciation (PW event) followed by a nonglacial interval including the Wellsch, Wascana and Redcliff event units, followed by a glacial interval, the Dunmore Glaciation (Table 2).

The PW Event "probably occurred 2 Ma ago and hence is the oldest Quaternary glacial event recognized in Canada" (Fenton, 1984) and may correlate with the basal part of the Sutherland Group as described by Christiansen (Klassen, 1989).

The Wellsch Nonglacial Interval (Table 2) consists of a gravel unit without Canadian Shield lithologies which is overlain by silt, sand, gravel containing stones originating from the Canadian Shield. Vertebrate fossils of Early Irvingtonian Land Mammal Age (Churcher, 1983) were found within this unit as well as volcanic ash dated at 630 and 690 Ka ago. This subunit is overlain by sand and gravel containing stones originating from the Canadian Shield.

The Wascana Nonglacial Interval (Table 2) is represented by the Wascana Creek Ash and associated clay described by Westgate et al. (1977) and has been dated at 600±40 Ka ago. Fenton (1984) suggests that some of the tills overlying the Wellsch stratified units may correlate with the Floral Formation of Saskatchewan (Table 2) and that the weathered horizon or the upper tills units of the Sutherland Group may have been exposed during the Wellsch Nonglacial Interval.

The Redcliff Nonglacial Interval (Table 1) is represented by a gravel and sand unit (Unit VI) and a clay and silt unit called Unit VII (Stalker, 1976). Wood, pollen and vertebrate fossils are present in these units. "Fauna from unit VI appears to be late Kansan to Yarmouthian and form Unit VII is Yarmouthian" (Fenton, 1984).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SANGAMONIAN
ILLINOIAN
YARMOUTHIAN
KANSAN
AFTONIAN
NEBRASKAN
NEBRASKAN
PRE-NEBRASKAN
TYPE "C" TILL
PLIOCENE
RANCHOLA-BREAN
LATE
EARLY
IRVINGTONIAN
LATE
EARLY
BLANCAN STAGE V
BRUNHES NORMAL
JARAMILLO
REVERSED
MATUYAMA
OLDUVAI
GAUSS
LOSTWOOD GLACIATION
WATINO NONGLACIAL INTERVAL
BURKE LAKE GLACIATION
OSLER NONGLACIAL INTERVAL
DUNMORE GLACIATION
REDCLIFF NONGLACIAL INTERVAL
WASCANA NONGLACIAL INTERVAL
WELLSCH NONGLACIAL INTERVAL
PW EVENT (GLACIATION)

Table 2. Quaternary Stratigraphy of Alberta (after Fenton 1984).

The Dunmore Glaciation (Table 2) was the first in which ice originating from the Canadian Shield covered most of Alberta, with units being exposed in the southern part of the province near Medicine Hat (Stalker, 1976). This glaciation is believed to be of Illinoian age (Stalker, 1976) and has tentatively been correlated to the Labuma till.

The Late Pleistocene events include the Osler Nonglacial Interval, the Burke Lake Glaciation, the Watino Nonglacial Interval and the Lostwood Glaciation (Table 2). The Osler Nonglacial Interval is represented by the Riddell Member of the Floral Formation (Table 1 and 2) and consists of 8 metres of sand. It is believed to be of Sangamonian age based on Late Rancholabrean fossils found in this unit. Vertebrate and invertebrate fossil records indicate a climate less severe than present with milder winters and cooler summers.

The Burke Lake Glaciation (Table 1) is represented by the upper till unit of the Floral Formation (Table 2) and is believed to be Early Wisconsinan as it is underlain by the Riddell Member (Sangamonian) and overlain in places by stratified sediment of the Middle Wisconsinan nonglacial interval by the Battleford Formation (Christiansen, 1973; SkaraWolf, 1981). This glaciation has covered the Prairies south of the United States border (Clayton and Moran, 1982) and may include many advances and retreats.

The Watino Nonglacial Interval (Table 1) consists of massive fine grained sediment which contains molluscs, ostracods, pollen and plant fossils located between units of proglacial lacustrine silt and clay. Radiocarbon dates on wood and peat range from 43.5 ±.62 Ka ago (GSC-1020) to 27.4 ±.85 Ka ago (I-4878, Westgate et al., 1972) and therefore Watino Nonglacial Interval is considered to be of Middle Wisconsinan age with maximum and minimum dates of 52 Ka to 23.7 Ka ago, (Fenton 1984).

The Lostwood Glaciation (Table 2) is late Wisconsinan and originated from the Keewatin ice center and covered most of south-central Alberta (Clayton and Moran, 1982). It is thought that southward and southwestward flow and later a southeastward flow of ice took place in Alberta and possibly extended into Montana (Clayton and Moran, 1982). In northeastern Alberta, the ice retreated approximately 13 Ka ago in an irregular manner with many readvances and stillstands (St-Onge, 1972; Matthews, 1980; Rutter, 1984; Dyke and Prest, 1987).

Andriashek (1985) completed the first detailed stratigraphic study in east central area, in the Sand River Map sheet located directly north of the Vermilion map sheet. He identified 4 glacial and 4 nonglacial formations (Table 3) based on subsurface and surface data. His youngest formation, the Grand Center Formation (Table 3), outcrops throughout the Sand River map sheet. It is composed of four members deposited by the Cold Lake Glacier. These include the Reita Lake and Hilda Lake members which were deposited by a ice lobe originating from the northeast, the Kehiwin Lake member deposited by a lobe originating from the north and the Vilna Member deposited in the northwest. All these diamictons have similar coarse sand mineralogy characterized by high contents of plutonic and metamorphic lithologies (Table 3). They were differentiated on the base of their texture, color, orientation of glacial ice-flow indicators and stratigraphic position (Andriashek, 1985). This uppermost till is the result of the last major glaciation, the Lostwood Glaciation, during the Late Wisconsinan and is correlated with Christiansen's(1968) uppermost glacial formation, the Battleford Formation (Table 1 and 3).

The Sand River Formation (Table 3) consists of sand and gravel and was deposited during the retreat of the Ardmore glacier during the last major ice event. This formation is possibly mid to late Wisconsinan (Andriashek, 1985).

The Marie Creek Formation (Table 3) was probably deposited by the Ardmore

Table 3 Quaternary Stratigraphy of the Sand River Area

modified from Andriashek and Fenton 1989

STRATIGRAPHIC UNIT NAME	EVENT	POSSIBLE AGE
Grand Center Formation	Cold Lake Glaciation	Late Wisconsinan
Hilda Lake Member	*Primrose Lobe*	
Reita Lake Member	*Primrose Lobe*	
Kehiwin Lake Member	*Seibert Lobe*	
Vilna Member	*Lac La Biche Lobe*	
Sand River Formation		Mid-Late Wisconsinan
Marie Creek Formation	Ardmore Glaciation	Early Wisconsinan
Ethel Lake Formation		Early Wisconsinan
Bonnyville Formation	Fort Kent Glaciation	Pre-Wisconsinan
Muriel Lake Formation		Pre-Wisconsinan
Bronson Lake Formation Glaciation	Cherry Grove	Pre-Wisconsinan
Empress Formation		Early Quaternary to Tertiary

Glacier (Andriashek, 1985). It shows strongly oxidized surfaces in many locations and for that reason is considered to be significantly older than the Grand Center Formation, possibly early Wisconsinan. This Formation is characterized by high carbonate content both in the coarse sand (1-2 mm) and clay and silt fraction (Table 3). The high amount of carbonate in this diamicton suggests a glacial provenance of Devonian carbonates which are present in northeastern Alberta (Green, 1970). Its generally sandy texture occasionally presents a clayey nature which may be explained by the incorporation of underlying glaciolacustrine deposits or by deposition of parts of this till into a glaciolacustrine environment (Andriashek, 1985). Andriashek has correlated the Marie Creek Formation with the Early Wisconsinan Floral Formation (Table 1) of Saskatchewan on the base of stratigraphic position, mineralogy, and the highly oxidized and jointed surface.

The Ethel Lake Formation (Table 3) is chiefly glaciolacustrine silt and clay, and locally sand and gravel, which were deposited either during the retreat of the Fort Kent Glacier or during the advance of the Ardmore Glaciation (Andriashek, 1985). The lack of weathering at the top of this unit, and its gradual contact with the base of the Marie Creek Formation suggest that this formation is slightly older than the Marie Creek diamicton and may also be early Wisconsinan.

The Bonnyville Formation was deposited during the Fort Kent Glaciation (Table 3). It is a clayey diamicton overlain by a much sandier diamicton often separated by thin stratified deposits. It is characterized by high quartz and low carbonate content in the coarse sand fraction (1-2 mm) (Table 3). Andriashek speculates that this formation may be pre-Wisconsinan or possibly Sangamonan.

The Muriel Lake Formation (Table 3) consists of sand and gravel and was deposited on top of the Bronson Lake glacial unit, either during the retreat of the Cherry Grove Glacier or by proglacial streams during the advance of the following ice event. This formation is assumed to be older than the Bonnyville Formation and is probably pre-Wisconsinan (Andriashek, 1985).

The Bronson Formation (Table 3) is the oldest glacial unit, deposited by the Cherry Grove Glacier. The Bronson Formation (Table 3) is characterized by a high clay content, a coarse sand mineralogy with low content of igneous and metamorphic lithologies, high quartz content, low carbonate content and high local bedrock content (Andriashek, 1985). It is assumed to be older than the Muriel Lake Formation and possibly early Quaternary in age. The high clay content, the distribution and stratigraphic position of this till may indicate a stratigraphic equivalence with the dark clayey lower member of the Sutherland Group in Saskatchewan (Table 1).

The Empress Formation (Table 3) includes: 1) sand and gravel without lithologies originating from the Canadian Shield; 2) a silt and clay unit overlain by; 3) glacial sand and gravel containing stones of lithologies originating from the Canadian Shield. This package of fluvial and proglacial deposits was called the Empress Group by Whitaker and Christiansen (1972) and was redefined for the Sand River area as the Empress Formation (Andriashek and Fenton, 1989; Klassen, 1989).

The lowermost gravel of the Empress Formation, which is composed mainly of local sandstones and of Rocky Mountain lithologies such as hard sandstone, quartzite, chert and limestone, is believed to have been deposited by drainage systems flowing eastward from the Rocky Mountains during the late Tertiary (Stalker, 1967; Whitaker and Christiansen, 1972; Fenton, 1984; Andriashek, 1985).

A well integrated system of valleys and tributaries was eroded into the Upper Cretaceous bedrock in this part of Alberta, with deposits of fluvial sands and gravels in the valley bottoms. Tertiary gravel is generally well sorted, well rounded and may be locally cemented. It rests directly and unconformably on the Cretaceous formations and is overlain by glacial deposits. It is locally known or described as white gravel, pea gravel or Saskatchewan gravel. Tertiary or preglacial sands and gravels were first identified by McConnell (1885) who noticed the absence of Shield bedrock material such as granite, gneiss or other bedrock lithologies of eastern provenance. These coarse fluvial sediments are often capped by a silt and clay unit and sand and gravel deposited by proglacial lakes and glaciofluvial streams from the oldest ice advance. The upper portion of this formation may be include clasts glacially transported by the ice (plutonic and metamorphic lithologies from the Canadian Shield) and deposited by proglacial glaciofluvial streams (Andriashek, 1985; Andriashek and Fenton, 1989).

2.5 FIELD METHODS

2.5.1 SURFACE GEOLOGY

The mapping of the surficial geology of the Vermilion-east area was part of a 1:250,000 scale mapping project conducted by the author for the Alberta Geological Survey. Air photo interpretation was done at the 1:40,000 scale prior to field mapping. Map units are defined according to their lithology, morphology, relief and classified into genetic and morphologic units. Ground truthing followed during the summers of 1983, and part of the summer 1984. Access is very good for most of the map sheet except in the northeast corner, north of the North Saskatchewan River. As a result, 90% of map units were visited except in that area. However, the morphology of the terrain units in that corner of the map were well defined on the air photos and the mapping is considered accurate in spite of the lower intensity of ground truthing.

Facies descriptions in the Vermilion map area were carried during the summer of 1986. During the previous years while mapping was carried out, significant exposures were identified for detailed section description. Reference sections and section locations are described in Appendix 4.

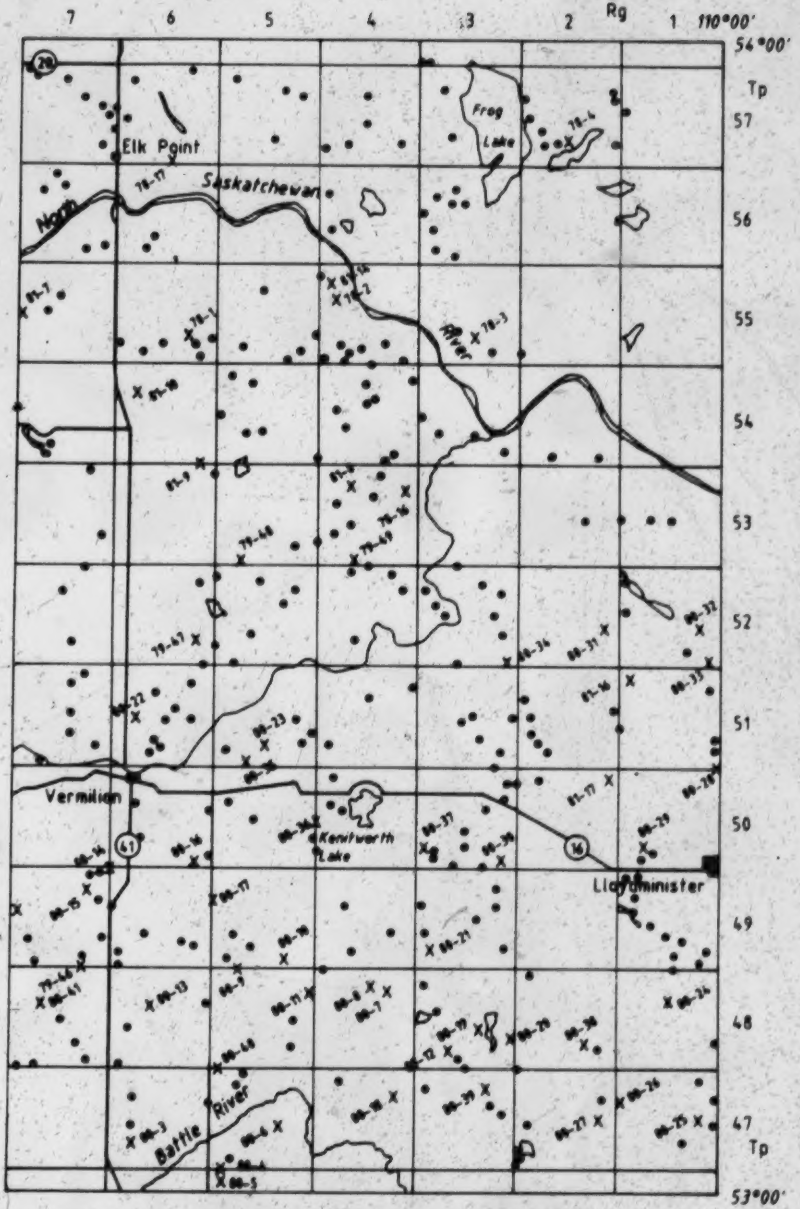
Stratigraphic data collected during the surficial geology survey are limited in scope due to shallow exposures. The larger exposures were measured and described using a facies scheme developed in the field.

2.5.2 SUBSURFACE DATA

A total of 268 lithologs were used after reviewing an estimated 700 lithologs generated from water well drilling, coal studies and other subsurface data available through the Alberta Environment records (Figure 7). Depth of boreholes, description of sedimentological properties and the distribution of the boreholes vary greatly through the Vermilion east map sheet and as a result they were used mainly to identify diamicton and stratified sequences, the presence of weathered surfaces and depth to bedrock.

A short joint drilling program was done in 1981 with Alberta Environment and the Alberta Research Council using a rotary drill for the purpose of testing stratigraphic interpretations. Seven of these boreholes (Figure 7) are included in this study area with a maximum depth achieved of 118 metres and bedrock penetration of 55 metres. Geophysical logs (electrical-resistivity logs) were also run in each of these holes. Side-wall samples weighing about 170 grams were collected at 5 feet (1.5 metre) intervals in the diamicton deposits. Diamicton samples were processed in the Alberta Research Council laboratory.

An extensive drilling program was initiated in 1978 by the Alberta Research Council and terminated in 1981. It covered the entire Vermilion map sheet (73E) with a total of 57 boreholes in the study area. A total of 35 boreholes yielded reliable data deemed sufficient to interpret Quaternary stratigraphy (Figure 7). A truck-mounted, solid stem auger drill was used and achieved depth of 58 metres in unconsolidated sediments and penetrated up to 5 metres in the bedrock. Continuous auger flight sampling provided good control on lithology, color, texture, general sedimentary characteristics, contacts and thickness of deposits. However the disturbed nature of the drilling samples did not allow for descriptions of sedimentary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80-23
Vermilion
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Kenilworth Lake
16
80-37
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Lloydminister
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Battle River

Figure 7: BORE HOLE LOCATION MAP

X Alberta Reseach Council boreholes and numbers

● Alberta Environment boreholes

features. Samples of about 500 grams were collected at one metre intervals and were subsequently brought to the Alberta Research Council laboratory to be processed, as were the samples from the Alberta Environment and Alberta Research Council drilling project.

2.6 CORRELATION METHODS

Detailed litholog analysis and laboratory work from the Alberta Research Council samples provided a basis for the identification and characterization of lithostratigraphic units. Diamictons, stratified deposits (silt, sand and gravel), weathered surfaces and contact with bedrock were identified from Alberta Research Council boreholes and are the primary characteristics used for correlation purposes.

The following properties were used to describe stratigraphic units; depth, color, matrix texture, total carbonates of the silt and clay fraction, and coarse sand mineralogy. Pebble counts (Shetsen, 1984) were not possible as the auger samples were only 500 grams and contained typically less than 15 pebbles each.

Upper samples from each diamicton unit (< 2 metres) were treated with caution, as surface processes can alter significantly the exposed deposit.

Diamicton color (of moist sediment) was classified with the Munsell Soil Color Chart and was used to define oxidized surfaces. Grain size analyses for this study were performed at the Alberta Research Council using a modified ATSM#D422-63 method. The clay, sand and very coarse sand percentages of diamicton samples were plotted on a depth versus grain size graph for each borehole. Means and standard deviations of these percentages were calculated for each stratigraphic unit.

Textural characteristics of diamictons have been used as an important criteria for correlation of Quaternary stratigraphic units by workers such as Westgate (1969), Pawluk and Bayrock (1969), Dreimanis and Fenton (1969), and Andriashek (1985).

Calcite, dolomite and total carbonate content of the silt and clay fraction were determined in the Alberta Research Council laboratory based on the method described by Dreimanis (1962) and Christiansen and Ross (1971). Matrix carbonate content has also been used with some success as a correlation tool by Dreimanis and Fenton (1969) and Andriashek (1985) in correlating till units.

Pedogenic processes and ground water movement may affect the carbonate content of unconsolidated sediments and caution was exercised in dealing with deposits close to a weathered surface. Generally, carbonate content was used as a correlation tool only in glacial units where samples were form at least 2 metres below the weathered surface and the entire unit was more than 5 metres thick.

The coarse sand (1-2 mm) fraction extracted during the grain-size analysis was dyed with alzurine dye according to the method described in Friedman (1959) to differentiate the dolomite and limestone grains. At least 200 grains per sample were examined under a microscope and originally divided into eight main groups; plutonic and metamorphic fragments, chert, quartz, quartzite, quartz sandstone, limestone, dolostone, and other local lithologies (siltstone, shale, ironstone, sandstone). Those categories represent main bedrock types which can help identify the provenance or direction of ice flow.

For example, the plutonic and metamophic lithologies were incorporated by glaciers flowing over the Canadian Shield and such lithologies are not present elsewhere in Alberta. Fine volcanic clasts and chert would indicate a western or Cordilleran origin and their very limited presence in coarse sand fraction of the Vermilion diamictons is probably due to the erosion of Tertiary gravels.

Most of the samples from which a coarse sand mineralogy count were done are subsurface samples. Chert, quartzite and quartz sandstone appeared in negligible quantity and were not used as a correlation tool. The author also found that in addition to their very low percentage, the differentiation between quartzite and quartz sandstone, and in a few cases, of quartz grains, was a rather subjective decision and counts varied with the operator. Therefore the quartzite and quartz sandstone percentages were not considered reliable.

When possible, primary structures such as stratification, grading or sorting plus secondary structures such as folding, faulting and jointing were logged.

Diamicton units bounded by stratified or weathered sediments were characterized by textural ranges and mineralogical properties. In stratigraphic intervals where properties of diamicton were quite consistent, means and standard deviations for the textural ranges, carbonate content and coarse sand mineralogy were calculated for the purpose of characterizing discrete units. Averages and trends of diamicton units, as well as relative stratigraphic position, were used to compare and define the lithostratigraphic units. The value of these diagnostic properties remained relatively constant in relationship with other units but did show variations within a unit over distance.

For example, a sandy diamicton rich in carbonate in the coarse sand fraction was consistently overlain by a clayey diamicton rich in igneous and metamorphic lithologies in the coarse sand fraction. It is therefore important to use the analytical data in conjunction with stratigraphic position within reasonable distance between boreholes.

The number of observations (analysed samples for each diamicton unit) was not sufficiently high to be treated statistically and the characteristics of the diamicton units were better used in a relative sense rather than in a numerical value. For these reasons, the interpreted stratigraphic units were not formalized into formations.

Once a general picture of the stratigraphy emerged, subsurface data from other sources (Alberta Environment, Alberta Transportation) were integrated to obtain a more complete distribution of stratigraphic units. Alberta Environment lithologs from water wells provided general information such as oxidized horizons, textural classes and distribution of stratified and unstratified deposits. Geophysical information was used to confirm stratigraphic interpretations.

2.7 STRATIGRAPHIC CORRELATION METHOD: COMMENTS

Although stratigraphic position was used as the principal correlation method, the physical properties of diamicton units were found an adequate stratigraphic tool if used with caution. For example, properties of diamicton units were found to be diagnostic when comparing boreholes located close to each other. However, when dealing with more distant boreholes, they are better used in a comparative sense.

It is also interesting to note that diagnostic properties of diamicton units were relatively quite constant throughout the study area except in areas of thin glacial deposits and glaciotectonic activity.

The most useful correlation analytical tool is coarse sand mineralogy. In thick diamicton units which are clearly defined by their stratigraphic position, discrete changes in the coarse sand mineralogy exhibited consistent patterns. Sand and clay percentages were useful. However, a diamicton interval would occasionally have a texture different from the type example of the diamicton unit represented by its stratigraphic position and coarse sand mineralogy.

A good example of this is illustrated on borehole R80VE3 (Appendix 3) where the third diamicton interval is very rich in carbonate and clayey, and stratigraphically corresponds to the typically sandy Diamicton Unit B. This unit is correlated with the Marie Creek Formation described by Andriashek (1985) which is locally associated with glaciolacustrine deposits. It is possible that locally this diamicton interval was in contact with glaciolacustrine environment, depositing a clay-rich diamicton. As the quality of subsurface samples collected for this study does not allow detailed sedimentary structure which may help identify changes of depositional environment, the use of matrix texture as a correlation tool is limited.

Diamictons in direct contact with bedrock also show wide ranges of both texture and mineralogy and and do not produce meaningful data except perhaps as indication of proximity to in situ or disturbed bedrock. Boreholes located in the thin thrusted moraine also show greater variety of textural range but the coarse sand mineralogy is still well defined enough to correlate units of sufficient thickness.

Glacial deposits thinner than 4 metres with no identifiable stratigraphic position were usually not correlated as they did not provide sufficient lithological or mineralogical information.

CHAPTER THREE SURFICIAL GEOLOGY

3.1 LEGEND EXPLANATION

The map notation system (Table 4) used here is based on the legend used by Fenton and Andriashek for other mapping projects in central Alberta (Andriashek et al. 1979; Fenton and Andriashek, 1983; Andriashek and Fenton, 1989). This system allows the map user to obtain rapidly the general lithology, morphology and relief of a polygon (an individual polygon being a single area defined by the unit boundaries on the map) and to attach a general genetic class to the landform described by the symbol. Not all symbols are present in all map units due to insufficient data. Map units are usually representative of the upper 3 metres and the symbol represents at least 75% of the map unit composition.

In areas of complex geology within a polygon boundary, the symbol + is also used to indicate the presence of up to three different units outcropping in any proportion or distribution. For the same reasons, when two morainic map units are present in the polygon, a complex genetic code is used.

The first letter or prefix (when present) is a lower case letter (Table 4) and refers to the dominant texture of the deposits as evaluated in the field. In morainic units, the composition symbol is absent and is usually composed of diamicton. Diamicton consists of unstructured, unsorted to very poorly sorted mixture of clay, silt, fine to coarse sand, pebbles, cobbles and boulders. Texture symbols describing two categories such as sg for sand and gravel may mean unsorted sand and gravel or interbedded sand and gravel.

The second letter is an upper case letter and indicates genesis. Seven major genetic categories were identified and are represented by a capital letter (Table 4). A second or third letter called a genetic modifier is usually added to the code to include a secondary genesis (e.g. MF = fluted moraine, FG = glaciofluvial)

Table 4 SURFICIAL GEOLOGY UNIT CLASSIFICATION

COMPOSITION (prefix)	GENETIC CLASS	GENETIC MODIFIER	MORPHOLOGY AND RELIEF (suffix)
a: SAND, SILT AND CLAY	O: ORGANIC	E: ERODED	d: DISCONTINUOUS
b: SAND AND SILT	C: COLLUVIUM	S: SLUMPED	dr: DRAPED
c: CLAY	F: FLUVIAL	D: DISSECTED	f: FLAT
f: SILT AND CLAY	E: EOLIAN	E: ERODED	h: HUMMOCKY
g: GRAVEL AND SAND	L LACUSTRINE	F: FLUTED	k: KNOBS
s: SAND	M: GLACIAL	G: GLACIAL	m :ROLLING
t: DIAMICTON	B: BEDROCK	IC: ICE CONTACT	r: RIDGES
r: BEDROCK, UNDIVIDED		N: TRANSVERSE	t: TERRACE
If blank, composition consists of diamicton		R: RUBBLE	u: UNDULATING
		S: STAGNANT ICE	v: VENEER (< 1m. thick)
		(S)C:CREVASSE	1: LOW RELIEF (< 3 m.)
		(S)D:DOUGHNUT	2: MEDIUM RELIEF (3 to 10 m.)
		(S)I: IRREGULAR STAGNANT ICE	3: HIGH RELIEF (>10m.)
		T: THRUST	

The suffixe (Table 4) describes the following: the continuity of a deposit (e.g. d = discontinuous), the morphology of the surface (e.g. h = hummocky), or the thickness of a unit (e.g. v = veneer), the amount of relief of a unit (e.g. 1 = less than 3 metres relief).

These letters and numbers can be combined and used in a complex fashion such as:

gFGm1	glaciofluvial gravel with a low rolling relief
bLGSv	veneer of glaciolacustrine silt and sand over stagnant ice
______ fh1	moraine with the entire unit having a flat to low hummocky
MSU	topography.

3.2 MAP UNIT DESCRIPTION

Map units are described in terms of their texture, morphology, relief, genesis and distribution. To avoid repetition, map unit complexes such as MTR (thrusted and rubble moraine complex) are described in Appendix 1.

ORGANIC DEPOSITS (O): marsh and bog deposits.

Organic marsh and bog deposits consist of peaty, woody, fibrous material or organic clay, which accumulates in poorly drained depressions. This unit can be thin (0.3 metres to 2 metres) and usually has a flat or low relief. It often rests on thin lacustrine deposits or directly on diamicton. Organic deposits generally are relatively small in area but can be very numerous in stagnant ice terrain and in the bottom of meltwater channels.

Organic deposits are usually poorly drained and often have a very shallow water table, which make them unsuitable for construction of any kind and unsuitable as well for the installation of septic systems. Where the vegetation cover is thick and the local drainage is poor, it is not unusual for the soil seasonal frost to linger until end of June. In some cases where organic matter is thick enough, these deposits can be harvested for peat or organic soil.

ERODED SLOPE DEPOSITS (CE): colluvial deposits from slope erosion, usually by creep, which accumulates at the base of slopes.

Colluvium is unsorted to poorly sorted, massive to poorly stratified, and ranges from clay to boulders in composition. The upper slope of this unit is usually steep and eroded, and the lower slope is covered with unsorted, poorly stratified clay to boulder size sediment. Thickness can be as great as 6 metres, generally increases downslope and is very variable laterally. This unit is recognized on valley, streams and meltwater channels sides, and on some of the larger scarp slopes.

The colluvial deposit itself is unstable and not suitable for construction or excavation. The steep slopes usually present obstacles for construction and may be still actively eroding.

SLUMP DEPOSITS (CS): colluvium deposited by slumping (usually rotational slumping) with the resulting scar or rotational fault.

Colluvium ranges from clay to boulders in composition and may be unsorted to poorly sorted, unstratified to poorly stratified, and may have preserved some of its original structure. The slope crowning these deposits is usually very steep and can be actively eroding. Thickness is highly variable and generally increases downslope. Slump deposits are common along the Battle River valley and along the Moose Hills channel.

These deposits are unstable and weak and are not suitable for construction or excavation. Seepage at the bottom of these slumps is common.

EOLIAN DEPOSITS (E): sediments deposited by the wind

Deposits consist of well sorted, well stratified to massive silt and sand. The finer-grained phase of these deposits is loess forming a massive silt blanket from 0.3 to 1 meter thick. Loess deposits usually occur as small, discontinuous veneers on glaciofluvial or morainic units and therefore are not mapped separately in this case.

Sand dunes consist of very well sorted, fine to medium-grained, cross-bedded or planar bedded to massive sand and can be as tall as 4 metres. Topography is hummocky to rolling, with medium relief. Sand dunes can be reactivated if the vegetation cover is broken. A large sand dune field (Plate 1) is located in township 55, range 5 (Figure 3 in back pocket). This unit covers a very minor portion of the area.

The texture and behavior of the fine sand makes it quite suitable for the establishment of houses and other low rise construction and septic systems, but the possibility of reactivating wind erosion of the dunes by removing the vegetation cover is often a deterrent factor for development on these deposits.

FLUVIAL SEDIMENT UNDIVIDED (FU): Sediments deposited by modern rivers, on the floors of the major river valleys and by small streams.

Small creek deposits are usually fine-grained silt to sand with a minor clay and gravel component. They are moderately well to well sorted and stratified and can be thicker than 3 metres. The topography is usually flat to gently undulating. The upstream section of a small stream deposit can include the eroded channel slopes.

The North Saskatchewan River is a meandering river of the type described in Walker and Cant (1984). Shaw and Kellerhals (1982) describe briefly the hydrology, fluvial geomorphology characteristics, the grain-size distribution and lithology of the coarser alluvial deposits of the North Saskatchewan River. According to their report, the Elk Point-Heinsburg river segment marks the boundary between gravelly fluvial deposits to the west and sandy deposits the the east. Thus within this study area, the North Saskatchewan River deposits are sandy rather than gravelly, with a flat to low hummocky or rolling topography. River deposits may be very thick for example at the Meridian bridge site (twp 53, rge 1, sec. 25) medium-grained to coarse-grained sand beds were excavated as deep as 10 metres (Plate 2). These sands usually contain a minor clay and gravel component and are a poor aggregate source. Battle River sediments with a maximum thickness of 8 metres, are composed mostly of silt and fine sand with minor gravel.

At most sites, this map unit may be subjected to flooding in the spring or have a shallow water table and therefore is not recommended for construction or septic tank location.

LACUSTRINE DEPOSITS (LU): Deposits of existing lakes.

These deposits are usually fine-grained (clay, silt and very fine sand) well sorted and distinctly stratified. They can be locally mixed, faulted or folded. Thickness varies from 0.5 to 2 metres and the morphology is usually flat to low hummocky. The sandy shoreline and nearshore facies are present only around the larger lakes (e.g. Frog Lake, Albert and Early Lakes. See Figure 3 in back pocket), and they can be considerably thick (more than 3 metres). Smaller lakes have siltier shorelines and thinner deposits (0.5 to 2 metres thick). This unit covers a very small portion of the area.

Poor drainage, due to the textural range as well as the unit position in low lying areas, and susceptibility to frost heaving make this unit unsuitable for construction of any kind.

GLACIOFLUVIAL DEPOSITS (FG): Sediment deposited by glacial meltwater.

Glaciofluvial deposits range from unsorted to well sorted, silty sand to coarse gravel which may contain a minor clay component and occasional boulders (plate 3). Morphology is usually low hummocky to rolling and occasionally undulating. Thickness may vary greatly within a map unit: it can be a thick knobby deposit whose thickness will range between 0.5 to 4 meters or a discontinuous veneer.

There are large glaciofluvial deposits in the Laurier Lake Lowland and around Vermilion, and in twp 53, rges 1 and 2 (Figure 3 in back pocket). Most meltwater channels such as Grizzly Bear Creek and Blackfoot Creek have associated discontinuous gravelly sand deposits. In some channels the map symbol MU + FG is used to indicate that glaciofluvial sediment may be present either overlying, underlying or mixed with diamicton in unknown proportions.

Most glaciofluvial deposits have a compositional range suitable for construction and topography may be the main limiting factor in some cases. Where deposits consists of coarse gravel, the percolation rate may be too fast for septic tank system to function properly. In rare cases, boulders will hinder excavation. This unit may be a good source of aggregates.

ICE-CONTACT GLACIOFLUVIAL DEPOSITS (FGIC): Sediment deposited by meltwater in contact with glacial ice.

Eskers are common ice-contact features and are represented on the map by the symbol FGICr1 or r2. Deposits consist of poorly to well sorted, poorly to well stratified sand, and sandy gravel-cored ridges with a diamicton blankets. Large diamicton inclusions, faulting and folding are very common due to the collapse of the supporting ice walls, floor or roof of ice during or after deposition. Eskers appear as continuous or discontinuous sinuous ridges which can be as as high as 15 metres and as long a 600 metres, with sides usually steeper than 30^{o} (Plate 4). They are associated with ice margins and terminal moraine complexes in the southeastern corner of the map, e.g. in sec 14 and 23 of twp 47, rge 1 (Figure 3 in back pocket). The steep topography of this unit makes it unsuitable for any kind of construction but the deposit itself may provide suitable aggregate.

Only a few kames in the Vermilion area were large enough to be mapped at the scale of the survey and are labelled FGICk1 or k2. Their composition is very similar to that of the eskers but their topography in this area is usually a single knob or a group of low, flat topped hills. A few small kames are present on the west side of the Landonville Ridge (Figure 3 in back pocket). The steep topography of this unit makes it unsuitable for any kind of construction but the deposit itself may provide suitable aggregate.

GLACIOLACUSTRINE DEPOSITS (LG): sediment transported by meltwater and deposited in glacial lakes.

These deposits are generally well sorted stratified clay and silt to fine sand. At the margins of the homogeneous deposits, a zone of mixed sediments is sometimes present as the result of either the collapse of the pre-existing walls of ice or slumping of other sediments into the lake. Folding and faulting are also commonly seen in these deposits due to the collapse of supporting ice walls where the lake bottom or margin rested close to ice cored material. Topography is flat to very low relief where the sediment was deposited on a stable base. Thickness may be up to 3 metres and this unit is a minor component of the map area.

Map units with a level surface can appear attractive for construction site but the unit is usually located in depressions and is fine-grained and therefore it has a potential for frost heaving and poor drainage.

ICE CONTACT GLACIOLACUSTRINE DEPOSITS (LGS): glaciolacustrine sediments originally deposited in ponded water at the surface of the glacier.

Sediments are well sorted and stratified clay and silt with minor sand with inclusions of diamicton, sand and gravel. Folding, faulting and mixing are common and deposits usually show collapse features such as pitted or hummocky topography with flattened crests, or a low relief depression surrounded by a rim of diamicton. This unit is usually draped over the underlying unit. Thickness varies between 0.2 to 1.5 metres. It is of minor extent and is usually associated with stagnant ice moraine unit as in township 51, range 1, section. 5 (Figure 3 in back pocket).

As this is usually a very thin unit, the properties of the underlying material will dictate the potential land use of the unit.

MORAINE (M): sediments in direct contact with and deposited by glacier ice.

Sediment in this area is composed mainly of fine grained diamicton (with an average texture of 35% clay, 30% silt, 30% sand with minor percentage of coarser material) but can include other sediments associated with the same landform or terrain type. Boulders, cobbles and pebbles include lithologies originating from the Canadian Shield of northeastern Alberta and adjacent Saskatchewan, quartzite, chert and carbonates from the Rocky Mountains or from underlying Tertiary gravels, and sandstone from northern Alberta. Topography varies between low relief(1 to 3 metres) undulating to high relief (more than 10 metres) hummocky. Thickness of diamicton units ranges between 0.3 metre and 70 metres. The thickness of moraine is greatest in the north east corner of the map and in buried valleys and generally thins southward (Figure 6).

Traditionally sediments deposited by the ice in a glacial environment were called till. New concepts in facies sedimentology emphasizes the important role of gravity, melt water and subglacial pressure in final depositional stages of deposits originating from the ice and promotes a more sophisticated classification of "glacial" sediments: for example original glacial deposits that underwent gravity flow and sorting by meltwater are called sediment gravity flow (Lawson, 1979, 1981) and by definition are not glacial deposit after resedimentation. Subglacial processes such as dilatation and meltwater percolation also contribute to textural and structural difference in tills (Dreimanis 1983). In a depositional environment as complex as the glacial environment, several depositional or erosional processes can be active at the same time, the degree and extent of reworking or contacts between till and non-till are not always visible (Boulton, 1980, Lawson, 1981, Mueller, 1983). In this thesis, the term 'till' will therefore be used in the same sense as that adopted by the Till Working Group of the Commission on Genesis and Lithology of Quaternary Deposits (Dreimanis 1982, 1983, 1987): "till is a sediment that has been transported and subsequently deposited by or from glacier ice, with little or no sorting by water".

In east-central Alberta, the material eroded, incorporated and deposited by the glaciers originates predominantly from fine-grained bedrock (shale, siltstone and fine-grained sandstone) which accounts for the fine-grained matrix of the diamicton.

Morainic units cover most of the map area and are subdivided into 9 major categories according to their genetic and morphological modifiers (Table 5). Morainic complexes (Table 5) are described in Appendix 1.

DISSECTED MORAINE (MD): moraine dissected by many closely spaced meltwater channels or gullies.

Sediment consists mostly of diamicton with minor sand and gravel. The exposed diamicton can be enriched in coarse or fine sediment depending on the degree of erosion and redeposition that took place. Original topography has been changed into alternating small channels and relatively level, interchannel surfaces, giving a hummocky to rolling appearance to the unit. Deposit thickness may be as deep as or deeper than the dissected relief. This unit covers a minor percentage of the area.

This unit can be suitable for residential development if the erosion is no longer active and if the slopes are reasonably low. Boulders can cause problems during excavation and poor site drainage may also complicate construction. Low

Table 5 MORAINE SUBUNITS IN THE VERMILION-EAST AREA

MD: DISSECTED MORAINE	moraine dissected by many closely spaced meltwater channels or gullies.
ME: ERODED MORAINE	moraine where the original surface as been eroded or washed to a low relief topography.
MF: FLUTED MORAINE	terrain composed of glacially streamlined moraine.
MN: NORMAL OR TRANSVERSE (ORIENTED) MORAINE	moraine exhibiting evidence of with glaciotectonic activity and perpendicular to the ice flow direction.
MR: RUBBLE MORAINE	moraine in which large blocks of foreign material are recognizable in the diamicton matrix and form the bulk of the landform.
MSC: STAGNANT ICE MORAINE AND CREVASSE FILLINGS	stagnant ice moraine with subparallel and intersecting ridges which result from the infilling of ice crevasses with glacial debris.
MSD: CIRCULAR (DOUGHNUT), STAGNANT ICE MORAINE	stagnant ice terrain consisting of circular hummocks with a central depression.
MSI: IRREGULAR STAGNANT ICE MORAINE	stagnant ice terrain consisting of irregularly shaped hummocks and sinuous ridges.
MT: GLACIOTECTONIC MORAINE	Masses of originally subglacial sediment incorporated, transported and deposited by a glacier more or less intact, or that has been subjected to changes of its physical properties due to the glaciotectonic stress.

permeability of the diamicton makes it unsuitable for septic systems.

ERODED MORAINE (ME): moraine where the original surface has been eroded or washed to a low relief topography.

Deposits consist of diamicton with discontinuous gravelly sand blankets. The diamicton has a variable matrix texture, locally enriched or depleted of fine sediment leaving a very sandy diamicton blanket overlying a clayer diamicton. Poorly defined channels are present mostly in the very low to medium relief map units. In map units with higher relief topography, gravel lags and thin silt sheets overlying the diamicton are common. Thickness of the eroded moraine averaged 1 metre. This unit covers a minor portion of the map as a separate unit, but is often included with other moraine complexes.

This unit can be suitable for residential development if the erosion is no longer active and if the slopes are reasonably low. Boulders can cause problems during excavation and poor site drainage may also complicate construction. Low permeability of the diamicton makes it unsuitable for septic systems.

FLUTED MORAINE (MF): terrain composed of (glacially) streamlined moraine.

Sediment is composed mainly of diamicton with stringers of poorly sorted sands with occasional inclusions of small bedrock blocks. When massive, the diamicton also shows minute joints and fractures resembling the platy structure as described in soils. Topography is low relief and undulating with streamlined alternating ridges and depressions parallel to each other. The ridges are usually 1 to 2 metres high, may be 100 metres wide and a few kilometres long.

The Northern Valley flutes (plate 1) south of the North Saskatchewan River appear to contain more sand stringers than the flutes north of the river which appear clayer and more massive. Their orientation is 40 ° southeast. The thickness of the fluted deposits cannot be established clearly. In this case, the morphological features themselves rest on very thick diamicton deposits. According to the stratigraphic interpretations, the fluted moraine averages 6 metres thick in the northern and central Irish Creek Plain and thins rapidly in its southern sector.

Two small fluting fields, one southwest of Frog Lake Uplands and one at Weeks Lake (Figure 3 in back pocket), are oriented northeast-southwest. Those fluting fields are covered with a discontinuous veneer of stagnant ice moraine.

This unit is suitable for residential development. However, boulders could cause problems during excavation and poor site drainage, specially in the inter-ridge depressions could also complicate construction. Low permeability of the diamicton makes it unsuitable for septic systems.

NORMAL OR TRANSVERSE (ORIENTED) MORAINE (MN): moraine associated with glaciotectonic activity and perpendicular to the ice flow direction.

Moraines are composed mainly of diamicton with local lenses of sand or gravel overlying bedrock cores which often show bedding subparallel to the surface slightly folded and probably in place. The topography is rolling, of low to medium relief and has the appearance of a poorly defined washboard terrain with irregular, discontinuous, parallel to subparallel ridges which are perpendicular to the local ice flow direction. Height of the ridges varies between 0.5 to 2.5 metres with an average of 1.5 metre. They are 10 to 30 metres long and are 5 to 10 metres wide. Thickness is greater than 3 metres. This unit is present south of the Vermilion River and west of the Landonville ridge (Figure 3 in back pocket) and in areas where both shallow bedrock and glaciotectonism are suspected.

This unit can be suitable for residential development. Boulders can cause problems during excavation and poor site drainage, especially in the inter-ridge depressions, may also complicate construction. Low permeability of the diamicton makes it unsuitable for septic systems. The presence of bedrock close to the surface in most areas of this map unit will cause a change of engineering properties within the landform with depth and may indicate disturbed siltstone and sandstone (folded, crushed or sheared). Any site studies should include relatively deep borehole investigation.

RUBBLE MORAINE (MR): moraine in which large blocks of pre-existing sediment are recognizable in the diamicton matrix and form the bulk of the landform.

Moraines may contain blocks of up to 5 by 8 metres of shale, siltstone, sandstone, and/or older sands, gravels or diamicton included in the diamicton host. The foreign blocks occasionally show primary structures such as bedding and secondary structures as faults and folds. Diamicton cover is usually 1 to 3 metres thick. The contact between the diamicton and the blocks ranges from a mixed zone to a sharp break. Morphology is hummocky, with relief up to 15 metres and thickness ranges between 5 and 15 metres (Plate 5). This moraine forms "a series of hills that form a train of debris down glacier from depressions composed of syngenetic and distinct blocks of pre-existing unconsolidated sediments and rocks" (Andriashek and Fenton,1989).

The rubble moraine around Raft Lake (Figure 3 in back pocket) has a hummocky, knobby topography with irregular slopes and does not present the continuous sinuous or ridged appearance of stagnant ice moraine or the central depressions often present in stagnant ice hummocks. It also shows faint streamlined features parallel to the Northern Valley flutes (Plate 5).

Rubble moraine also forms part of the larger thrust feature in the Blackfoot Hills (Figure 3 in back pocket). There, it very difficult if not impossible to define the exact boundaries between rubble and thrusted moraine particularly in areas of shallow bedrock with a hummocky and dissected relief as in the Blackfoot Hills.

This moraine type is mostly unsuitable for residential development primarely because topography is usually steep. In areas where relief is not a problem, rapid changes of lithologies can be expected and therefore of sediment properties and behavior

STAGNANT ICE MORAINE (MS): terrain formed from the lateral and downward movement of sediment as a result from the melting of supporting buried ice.

The reworked diamicton includes sorted sediments, such as thin sands and gravels stringers, clay and silt lenses, and bands of diamicton. The diamicton itself forms at least 80 % of the material and may appear massive or as mixed, interbedded bands and lenses of diamictons of variable textures. These textural changes are not always obvious from bulk sample analysis but are clearly visible through differential weathering on exposed sections. Topography is hummocky to rolling with a medium to high relief. Thickness varies from 2 to 10 metres, generally the higher the relief the thicker the unit.

This moraine covers a large portion of the map and has been divided into 3 subunits (MSC, MSD, MSI) based on morphology (Table 5). It is present in complex morainic units as well.

Stagnant Ice Moraine and Ice Crevasse Filling (MSC): stagnant ice moraine with subparallel and intersecting ridges which result from the infilling of ice crevasses with glacial debris.

This type of moraine consists mainly of diamicton with poorly sorted to unsorted silty to gravelly sand bodies. These inclusions can be lenses, stringers or bands, can be of variable shape, size and orientation, and can show deformation such as micro-folding, faulting, high angle bed repose and mixing. The diamicton itself has a variable texture. Some of the larger ridges have a high percentage of gravelly material but this is still much less than the proportion of gravel in the eskers present in the same area. The arcuate ridges are 0.5 to 2 metres high, 50 to 150 metres long and rest on very low relief stagnant ice moraine (Plate 6). Some of the ridges are superimposed and perpendicular to each other. Thickness is generally less than 2 metres.

This unit is present mostly in the southern part of the Northern Valley lowlands, with the best examples in townships 48 and 49, ranges 1 and 2 (Figure 3 in back pocket). The orientation of the ridges has two strong trends: one parallel to the flutes located directly north west of the crevasses fillings and a trend perpendicular to it.

This coarsely textured diamicton is usually a discontinuous and thin deposit and therefore the properties of the underlying finer grained diamicton will control the geotechnical behavior of this unit. This unit can be suitable for residential development. Boulders can cause problems during excavation and poor drainage may affect some sites. Low permeability of the diamicton makes it unsuitable for septic systems.

Circular (doughnut) Stagnant Ice Moraine (MSD): stagnant ice terrain consisting of circular hummocks with central depressions.

Moraine is composed of diamicton with minor glaciolacustrine or glaciofluvial sand, silt, clay or gravel deposits. Surfaces and sides of the hummocks may have a composition different from the center. In many hummocks, the central depression is partially filled with poorly stratified, poorly sorted fine-grained sediments.

Sections through such hummocks south and east of Frog Lake showed bands of very sandy diamicton mixed with massive and clayey diamicton on the rim of the hummocks and mixed clay and silt beds with minor sandy diamicton bands in the central depression. Morphology of the unit is hummocky with moderate relief, and thickness is usually more than 3 metres.

This unit covers little of the area and is always associated with irregular stagnant ice moraine. High relief and poor drainage may present problems during construction or cultivation.

Irregular Stagnant Ice Moraine (MSI): stagnant ice terrain consisting of irregularly shaped hummocks and sinuous ridges.

This map unit consists of clayey diamicton as described in MS, with associated minor glaciolacustrine and glaciofluvial deposits. Morphology is low to high relief, and consists of sinuous usually enclosed ridges with poorly drained depressions (Plate 7). Thickness is usually more than 3 metres.

Small ice-walled streams and ice-walled lakes were observed in the Frog Lake area but are too small to be identified on the map. Margins of disintegrating ice blocks can be reconstructed in places using the drainage pattern between blocks and the variation in morphology. Closed ridges of irregular to circular shape, moraine plateaux, and small rimmed moraine plateaux are present in the Frog Lake Uplands (Figure 3 in back pocket).

This unit covers most of the north east and south west portion of the area. High relief and poor drainage may present problems during construction or cultivation.

GLACIOTECTONIC MORAINE (MT): Masses of originally subglacial sediment incorporated, transported and deposited by a glacier more or less intact, or that has been subjected to changes of its physical properties due to the glaciotectonic stress.

This map unit may contain any material underlying the ice at time of disturbance: bedrock, sands and gravels, silt and clay, older glacial deposits (Plate 8). The disturbed deposits may be faulted, folded, sheared, mixed with till, or underlain by younger glacial material. Topography includes ridges or hills often of a composite nature with an individual feature being composed of a series of smaller arcuate ridges as in twp. 48 rge. 4 (Figure 3 in back pocket).

Occasionally,individual hills or ridges may be situated immediately down from a depression which was later filled with water to form a lake. This association of a MTEand MTk2 polygons (as in twp. 47 rge. 4) is also called a hill-hole pair by Andriashek and Fenton(1989). However, as is the case in many other locations in the Prairies, there are areas where the thrusted deposits can only be detected from field work observations or from drilling information. It is very difficult to predict how much, or to which depth, material is disturbed or the exact distance it has travelled. In most cases these maps units are generally thicker than 3 meters and may exceed 60 metres.

This unit is present on the north side of the North Saskatchewan River by the Meridian bridge, north and east of Frog Lake and in a large portion of the Blackfoot Hills where folded and faulted sandstone beds are present (Figure 3 in back pocket).

The variety of material incorporated into this terrain results in abrupt lateral and vertical changes of composition. The shear planes, folds and faults resulting from the thrusting of the sediment represent planes of weakness and this terrain may have a lower strength than expected. Excavations and cuts into this unit may be prone to slumping particularly if the cut is oriented perpendicular to the direction of these planes of weakness.

CHAPTER FOUR LITHOSTRATIGRAPHY

4.1 INTRODUCTION

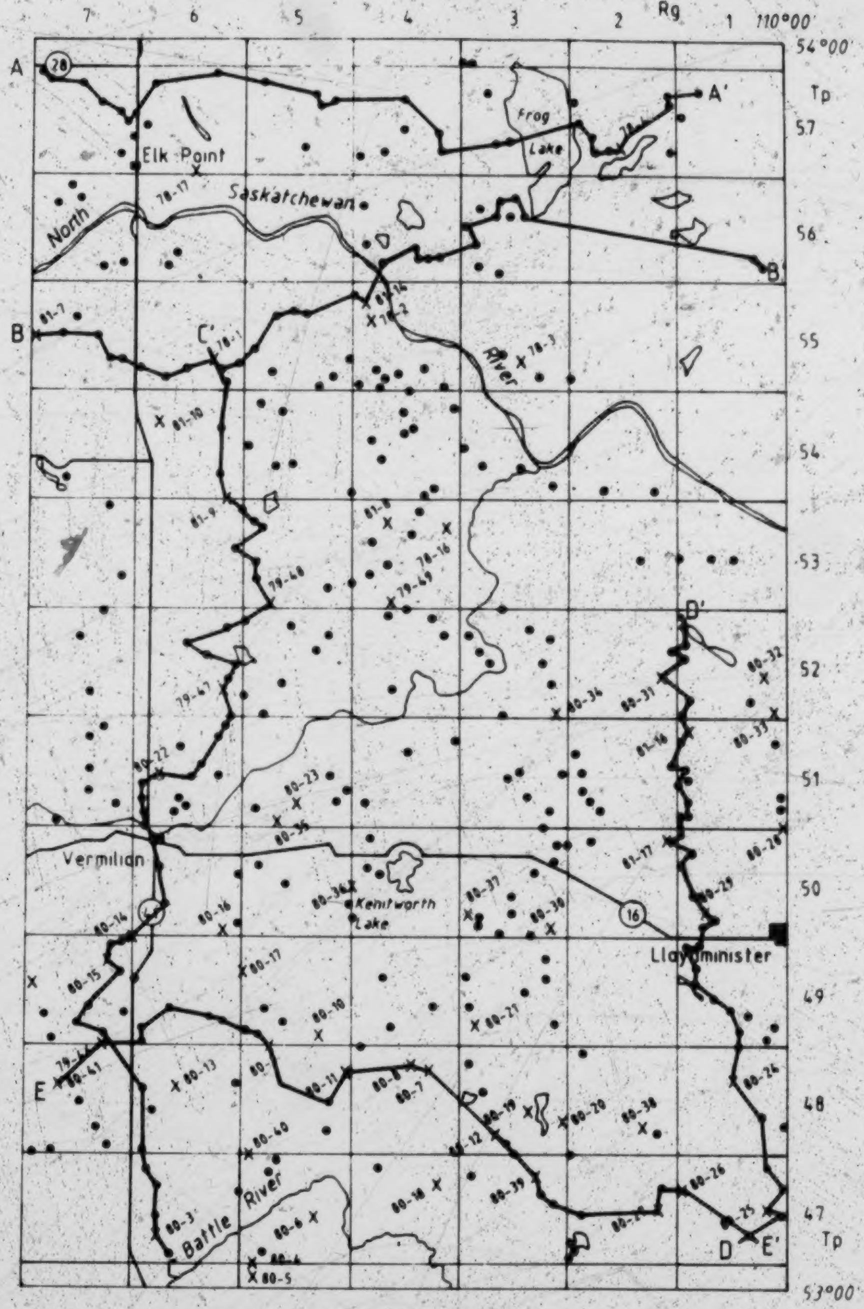
The stratigraphy of the Vermilion-East area is determined mainly from subsurface information. Exposures of diamicton units throughout the area are numerous but thin, the relief being in most case less than 5 metres and as a result only one stratigraphic diamicton unit is exposed. Quaternary deposits are quite thick in the north and east portions of the map area, especially in the buried valleys (e.g. Vermilion paleo-valley on Figure 5), and are considerably thinner in the south and west portion (Figure 6). The main sources of subsurface information are from the Alberta Research Council and Alberta Environment lithologs and geophysical logs (Figure 7). Six lithostratigraphic units composed of diamicton are identified and described in this chapter. Stratified units are present between the diamicton units. However they were not sampled, analyzed or described and are therefore identified solely by their stratigraphic position. Five cross sections across the map area provide representation of the stratigraphy (Figures 8, and 9 to 13 in back pocket).

4.2 LITHOSTRATIGRAPHY

Reference boreholes for each diamicton unit are listed and the data summarized in Appendix 2. Data for significant boreholes are presented in Appendix 3. The low density of boreholes allows only limited comments about unit distribution and thickness. As mentioned earlier the stratified units were not sampled and are identified by their stratigraphic position.

4.2.1 STRATIFIED UNIT A

Sand and gravel overlying bedrock in the bottom of preglacial channels are identified on Alberta Environment geophysical and lithological logs . No such deposits



Rg
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6
5
4
3
2
1
110°00'
54°00'
53°00'
Tp
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56
55
54
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48
47
A
A'
B
B'
C'
D'
D
E
E'
28
16
Elk Point
North
Saskatchewan
River
Frog
Lake
Vermilion
Kenilworth
Lake
Lloydminster
Battle
River
78-17
81-7
78-1
81-10
81-9
79-48
79-47
79-49
78-16
78-3
80-22
80-23
80-35
80-36
80-14
80-15
80-16
80-17
80-10
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80-18
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80-4
80-5
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80-33
80-28
80-29
81-16
81-17
80-26
80-25
80-41
79-1

Figure 8 CROSS SECTION LOCATION MAP

X Alberta Reseach Council boreholes and numbers

• Alberta Environment boreholes

were described or sampled during the Alberta Research Council drilling program. Drillers' logs describe gravelly deposits resting on bedrock as white sand and gravel, white pea gravel, or occasionally as Saskatchewan sand and gravel. In places, this unit forms a sequence of gravel overlain by silt and clay which in turn is overlain by sand. This sequence is identified in a few places in preglacial valleys on the geophysical logs mainly in the Frog Lake area in cross sections (Figures 9 and 10 in back pocket).

4.2.2 DIAMICTON UNIT A

DESCRIPTION

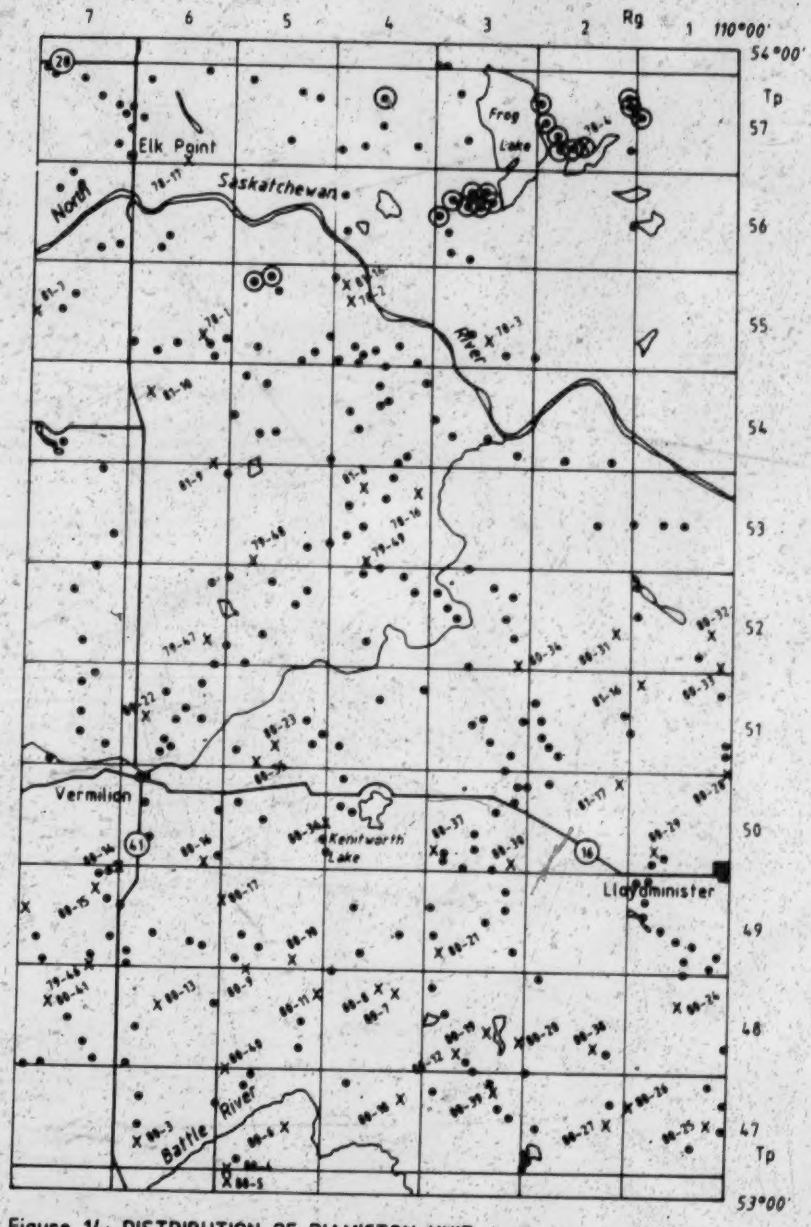
This unit does not outcrop in the survey area and is identified solely by the stratigraphic position seen in a few Alberta Environment lithologs and electric logs. The low resistivity of this unit indicates a very clayey texture and some lithologs describe a very dark brownish gray to very dark gray color with occasional boulders or gravel lenses. This diamicton is identified by its stratigraphic position and its very low resistance in electric logs. It appears to be more clayey than all other diamicton units and usually rest on bedrock or on Stratified Unit A.

DISTRIBUTION AND THICKNESS

Diamicton Unit A is present north and west of the Landonville Ridge in the deep buried valleys by Frog Lake and Lloydminster (Figures 9 and 10 in back pocket and 14). The thickness of this unit ranges from 5 to 26 metres and it is possible that this diamicton has a wider distribution. However its lateral extent could not be traced due to the low density of deep boreholes.

4.2.3 STRATIFIED UNIT B

Stratified sand and gravel occasionally overlies Diamicton Unit A. In some cases, Stratified Unit B sit directly on bedrock and does not occupy a preglacial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Vermilion
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Kenilworth Lake
16
Lloydminster
Battle River

Figure 14: DISTRIBUTION OF DIAMICTON UNIT A

X Alberta Reseach Council boreholes and numbers

• Alberta Environment boreholes

◎ Diamicton Unit A identified

channel. In most cases, it is overlain by Diamicton Unit B. This unit is identified mainly by its stratigraphic position. Where it was intersected in Alberta Research Council boreholes, it was described as containing plutonic and metamorphic clasts or granules of Shield provenance. In those cases, it is mineralogically different from the preglacial sand and gravel but not from other younger stratified deposits.

4.2.3 DIAMICTON UNIT B

DESCRIPTION

Diamicton Unit B (Figure 15a) was identified by: 1) its stratigraphic position; 2) by low content of plutonic and metamorphic rocks, high quartz and local bedrock percentages in the coarse sand fraction; 3) the low carbonate contents in both the coarse sand fraction and the silt and clay fraction; and 4) a matrix texture of nearly equal sand and clay content (Table 6). The top of this unit is commonly oxidized.

DISTRIBUTION AND THICKNESS

Diamicton Unit B does not outcrop but is present north of the North Saskatchewan River and east of the Landonville Ridge (Figures 9, 10 and 11 in back pocket and 16) at elevations between 620 metres to 560 metres. Its thickness varies from 5 to 50 metres and is generally thickest in the buried valleys. South and west of the Landonville Ridge, it appears to be thinner and discontinuous (Figures 12 and 13 in back pocket).

4.2.5 STRATIFIED UNIT C

Stratified sand and gravel are found overlying Diamicton Unit B and vary in thickness from 2 metres to 8 metres in buried valleys. This unit is identified by its stratigraphic position.

Table 6 Summary of analytical properties of the Glacial Units in the Vermilion map area

GLACIAL			TEXTURE			MATRIX		COARSE SAND MINERALOGY				
UNIT		SD%	CLAY%	C. SD%	CO_3	CR%	Q%	LST%	DST%	LOC%	QZT%	QSS%
UNIT F	**mean**	**34.7**	**32.2**	**1.4**	**8.4**	**56.0**	**26.4**	**3.2**	**3.0**	**3.6**	**1.4**	**1.7**
	std dev	2.7	3.5	0.1	1.0	4.3	1.4	0.4	1.2	1.9	0.6	0.7
UNIT E	**mean**	**40.7**	**30.7**	**1.5**	**7.8**	**53.9**	**32.8**	**2.8**	**3.0**	**3.1**	**1.6**	**1.6**
	std dev	4.1	4.4	0.3	1.2	2.4	1.9	0.6	0.9	1.3	0.3	0.9
UNIT D	**mean**	**31.4**	**39.3**	**1.2**	**8.3**	**57.5**	**29.6**	**2.3**	**3.1**	**2.6**	**1.4**	**1.4**
	std dev	3.9	4.5	0.3	1.6	5.9	4.0	0.9	1.6	0.7	0.7	0.8
UNIT C	**mean**	**38.8**	**32.1**	**2.0**	**9.9**	**51.1**	**29.5**	**5.4**	**5.2**	**4.9**	**1.5**	**1.1**
	std dev	5.96	6.0	0.7	1.7	5.2	4.5	2.7	2.2	2.8	0.8	0.6
UNIT B	**mean**	**36.7**	**34.5**	**1.8**	**7.2**	**46.6**	**39.9**	**2.6**	**3.1**	**5.0**	**1.3**	**0.9**
	std dev	7.5	3.8	0.5	2.7	0.9	2.5	0.5	1.8	1.0	1.0	0.4

Table 7 Summary of analytical properties of the Sand River Formations (modified from Andriashek, 1985)

FORMATION		TEXTURE		MATRIX		COARSE SAND MINERALOGY				
OR MEMBER	SD%	CL%	C.SD%	CO_3	CR%	Q%	LST%	DST%	LOC%	QZT% +QSS
REITA LAKE	38	36	1.7	11	69	25	2	3	0.8	1.2
KEHIWIN 43	25	2	8	62	29	3	3	1.3	0.9	
VILNA	32	36	1.2	11	64	28	3	3	1.3	1.2
MARIE CREEK	41	29	2.7	17	61	21	4	13	1.5	0.7
BONNYVILLE (EASTERN FACIES)	48	24	2.8	10	58	34	3	2	0.9	1.6

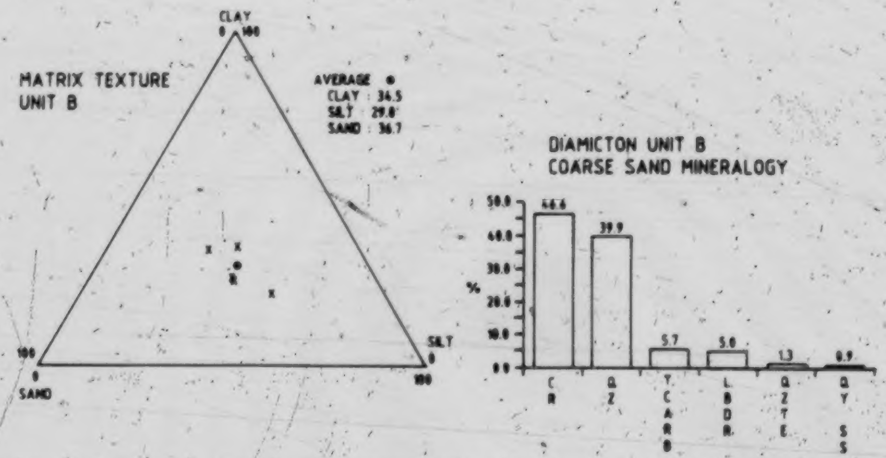


Figure 15a: Matrix texture and coarse sand mineralogy of diamicton unit B

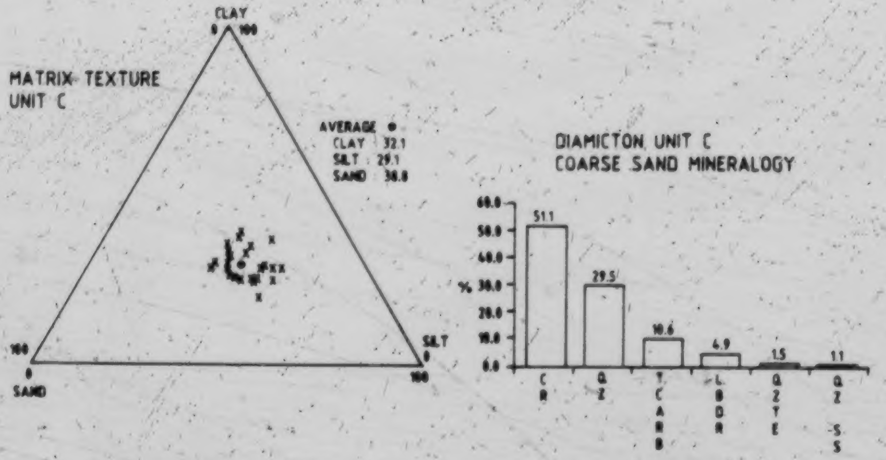
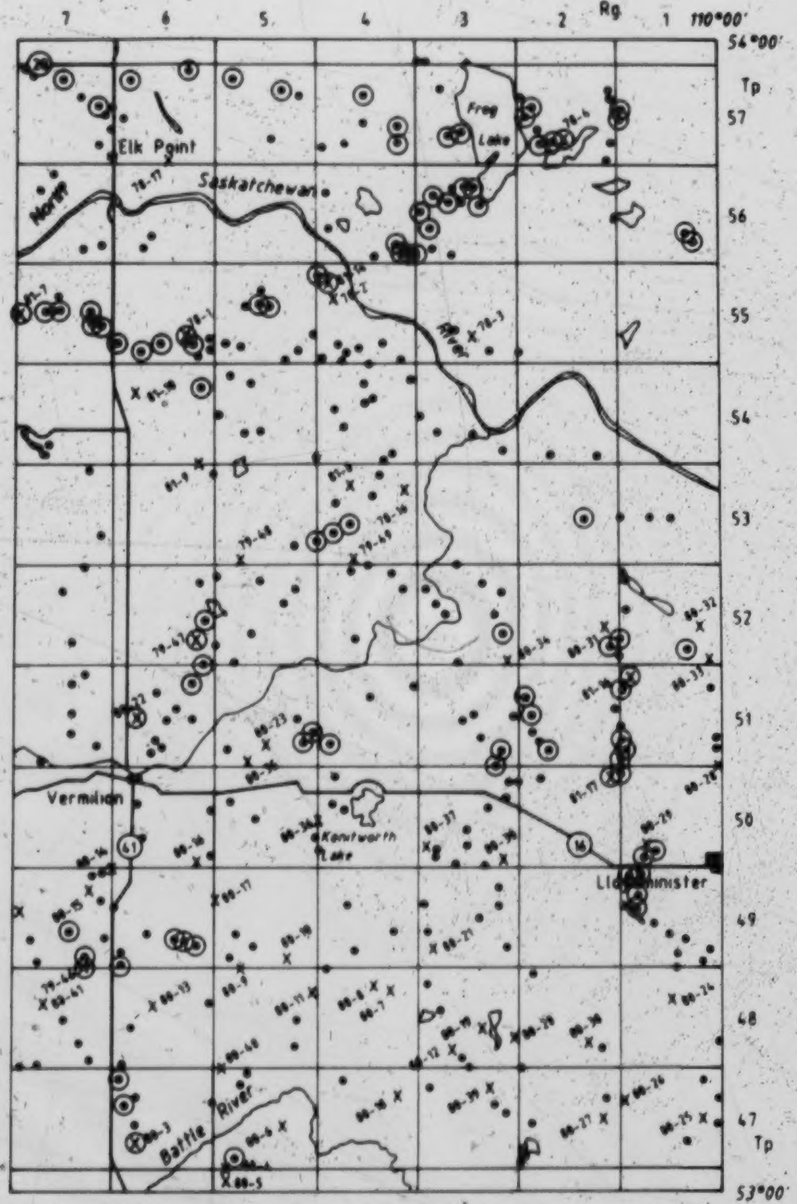


Figure 15b: Matrix texture and coarse sand mineralogy of diamicton unit C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Saskatchewan
River
Frog Lake
Vermilion
61
Kenilworth Lake
16
Lloydminster
Battle River

Figure 16: DISTRIBUTION OF DIAMICTON UNIT B

- X Alberta Reseach Council boreholes and numbers
- • Alberta Environment boreholes
- ○ Diamicton Unit B identified

4.2.6 DIAMICTON UNIT C

DESCRIPTION

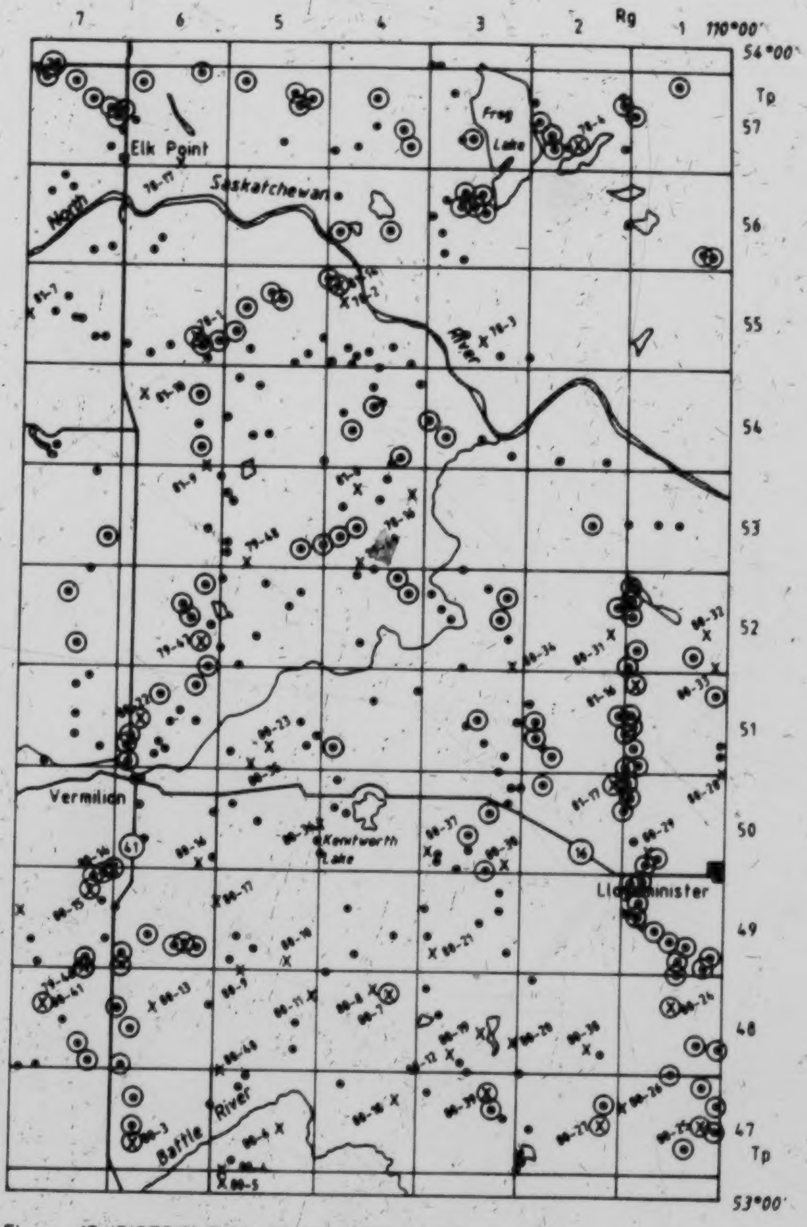
Diamicton Unit C (Figure15b) is identified by 1) stratigraphic position, 2) sandy matrix texture with a high coarse sand fraction percentage, 3) high carbonate content in the silt and clay fraction and in the coarse sand fraction and 4) higher plutonic and metamorphic lithologies and lower quartz than unit B (Table 6). Strong oxidization and iron stained joints were commonly described in the upper 5 metres of this unit. The textural distribution of this unit had a wider range than other units and in places, textures were dominated by clay with the stratigraphic position and mineralogical properties still being diagnostic of Diamicton Unit C. The contact with an overlying diamicton unit is often marked by a an abrupt change from the strongly oxidized, ironstained upper protion of Unit C to unoxidized diamicton or by a well defined break in textural and mineralogical properties.

DISTRIBUTION AND THICKNESS

This unit is present throughout the map are but is thickest north and east of the Landonville Ridge. It outcrops in a discontinuous and random pattern in the Blackfoot Hills and in a small flute field by Weeks Lake (Figures 11, 12, 13 in back pocket and 17). Thickness varies from 5 to 20 metres.

4.2.7 STRATIFIED UNIT D

Sand and gravel is present some places between Diamicton Unit C and other overlying diamicton units. These stratified sediments are associated locally with well stratified, well sorted clay and silt which are probably of a glaciolacustrine origin. This unit is identified by its stratigraphic position, thins southeastward and is absent in the southwest corner of the area.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North
Saskatchewan
River
Frog Lake
Vermilion
Kenilworth Lake
Lloydminster
Battle River
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Figure 17: DISTRIBUTION OF DIAMICTON UNIT C

- X Alberta Reseach Council boreholes and numbers
- • Alberta Environment boreholes
- ○ Diamicton Unit C identified

4.2.8 DIAMICTON UNIT D

DESCRIPTION

In boreholes, this diamicton is described as a dark grayish brown to very dark grayish brown silty clay. It usually has a low percentage of coarse fragments and pebbles. In sections, it has a silty clay to clayey silt matrix texture with a low pebbles and coarse fragment content, rare boulders and is usually oxidized to depth of 2.5 metres. Diamicton Unit D is characterized by 1) a coarse sand mineralogy with high content of plutonic and metamorphic lithologies, and 2) low quartz, carbonate and local bedrock content (Figure 18a). A small to coarse blocky structure was most common. When joints are present they are usually columnar and slightly ironstained. Large bedrock inclusions are present in road cuts north of the Meridian Bridge and northeast of Frog Lake.

DISTRIBUTION AND THICKNESS

This unit outcrops mostly in the northeast portion of the map (Figures 9 and 10 in back pocket and 19) where the thickness ranges from 5 to 25 metres, with an average thickness of 15 metres. This area is characterized by high relief hummocky topography with occasional large bedrock inclusions in the hummocks. In the Northern Valley Plain, Diamicton Unit D is usually overlain by Diamicton Unit E. West of the Landonville Ridge, this unit outcrops discontinuously in the rubble and thrusted terrains, and cannot always be definitely identified.

4.2.9 DIAMICTON UNIT E

DESCRIPTION

In boreholes, this unit is described as a grayish brown to dark grayish brown clayey sand to sandy silt and is usually a massive diamicton with a low percentage of coarse fragments and occasionally has a high content of pebbles . In exposures, it has similar matrix texture with low pebbles and clasts content, rare boulders and is

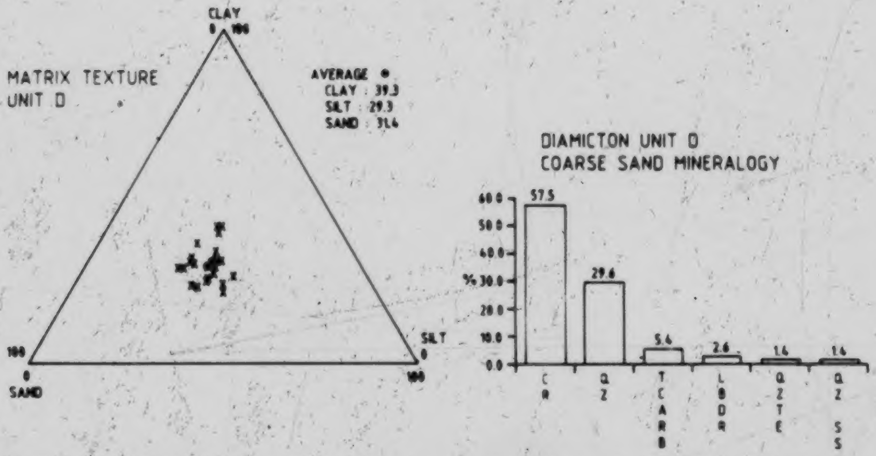


Figure 18a: Matrix texture and coarse sand mineralogy of diamicton unit D

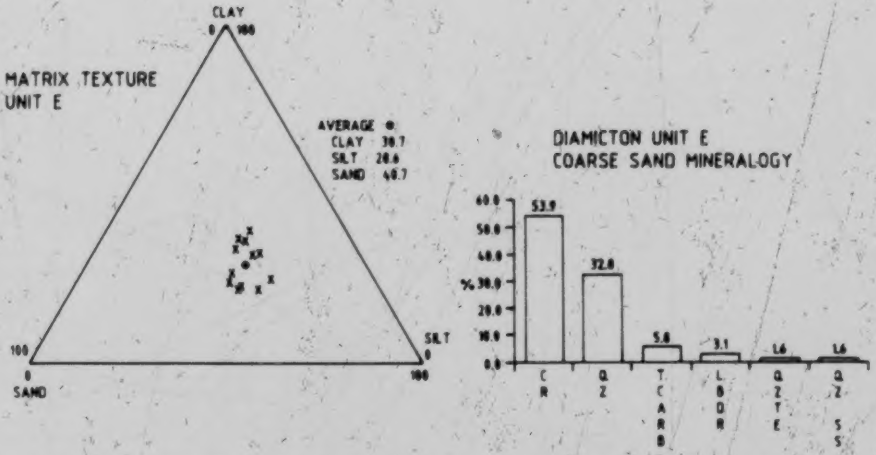
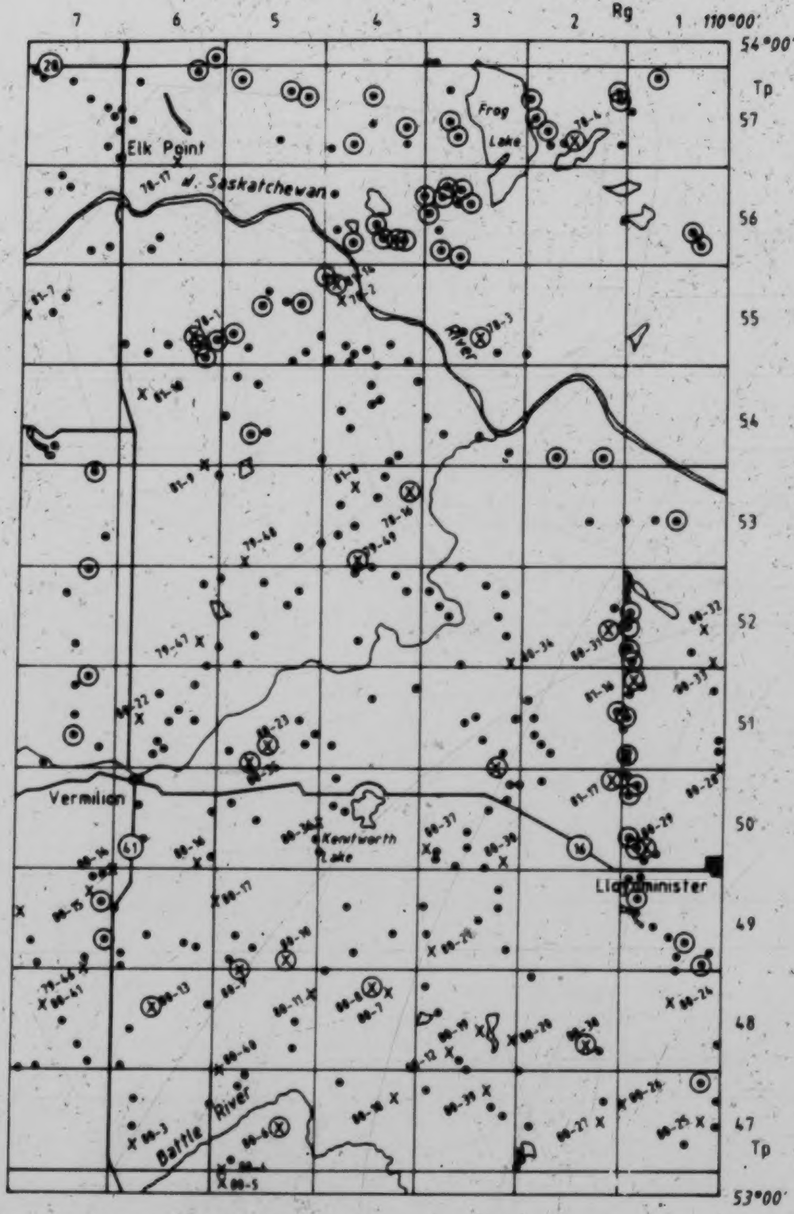


Figure 18b: Matrix texture and coarse sand mineralogy of diamicton unit E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Kenilworth Lake
Lloydminster
Battle River
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Figure 19: DISTRIBUTION OF DIAMICTON UNIT D

X Alberta Reseach Council boreholes and numbers

• Alberta Environment boreholes

○ Diamicton Unit D identified

usually oxidized to depth of at least 2.0 metres. A few bedrock inclusions are present in some hummocks north of the Vermilion River. This unit has 1) high plutonic and metamorphic lithology content, 2) low quartz content in the coarse sand fraction, and 3) low carbonate content both in the coarse sand fraction and matrix (Figure 18b). Diamicton Unit E has a sandier matrix than Unit D (Table 6), has a lower carbonate content in coarse sand and in matrix than Unit C and higher plutonic and metamorphic lithology content, lower quartz content in the coarse sand fraction than Unit B.

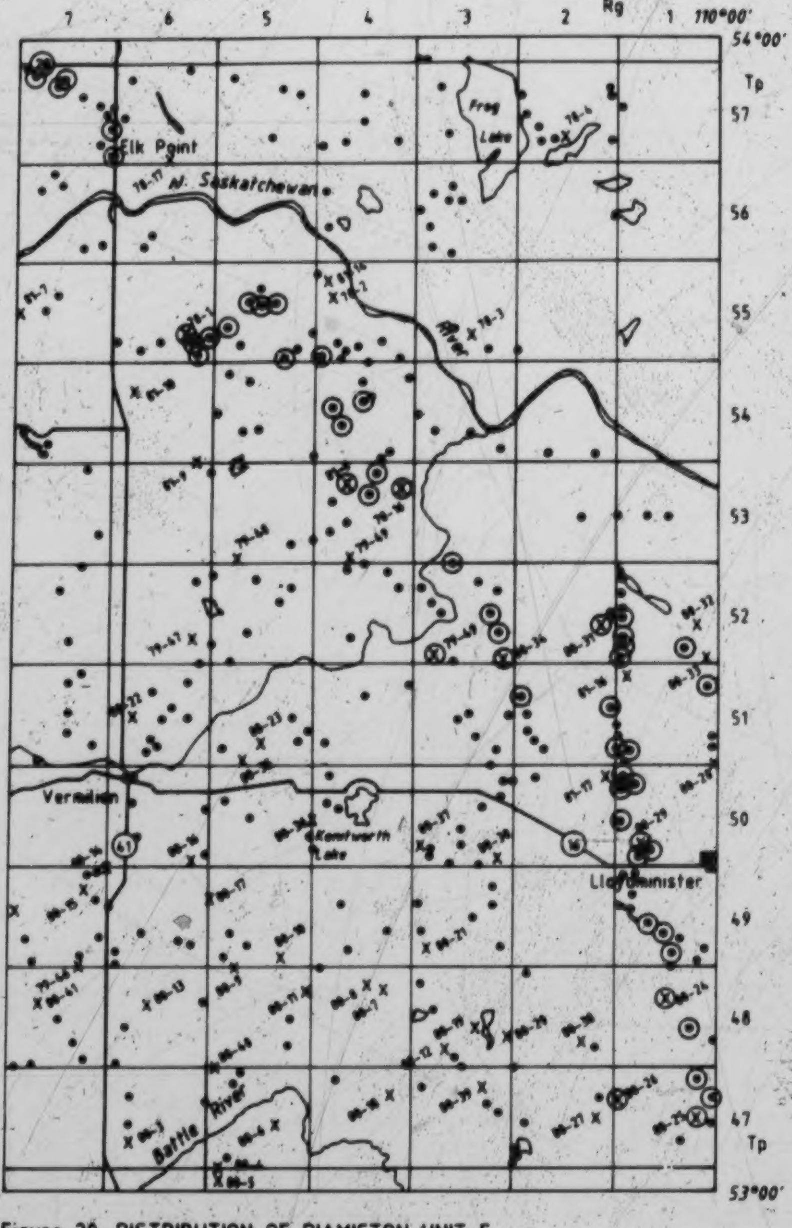
DISTRIBUTION AND THICKNESS

Diamicton Unit E was identified east of the Landonville ridge only and has a well defined distribution (Figure 20). It outcrops in the Northern Valley Lowland only where the terrain is glacially fluted northwest-southeast and in areas of thin ice disintegration and ice crevasse moraine (Figures 12 and 13 in back pocket). Its thickness is greater west of the Vermilion River, where it ranges from 8 to 24 metres and averages 11 metres. East of the Vermilion River, the fluted terrain disappears and the sandy Diamicton Unit E is restricted to thinner ice disintegration moraine (3 to 10 metres thick) which gradually becomes discontinuous south of township 48.

4.2.10 DIAMICTON UNIT F

DESCRIPTION

Textural and mineralogical properties of Unit F cover broad ranges and as a result there is no definite "fingerprint" of this unit (Table 6). This is probably due to the fact that this diamicton is present in a glaciotectonic area and in most cases is a thin blanket or veneer of diamicton resting directly on bedrock. It appears to be close in composition to Diamicton Units B and D but its thin and discontinuous distribution does not allow even a general definition of its properties.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Elk Point
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Frog Lake
Vermilion
Kenilworth Lake
Lloydminster
Battle River
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Figure 20: DISTRIBUTION OF DIAMICTON UNIT E

x Alberta Reseach Council boreholes and numbers

• Alberta Environment boreholes

○ Diamicton Unit E present

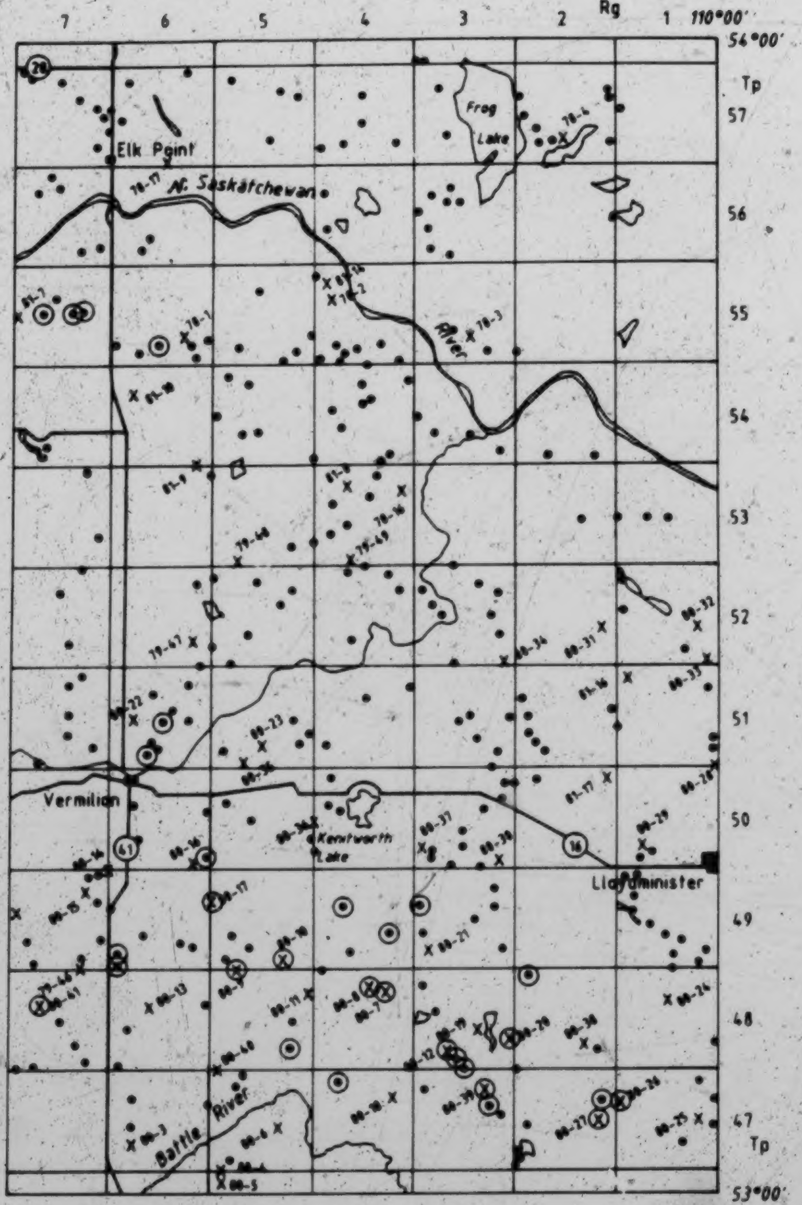
DISTRIBUTION AND THICKNESS

Diamicton Unit F outcrops in the southwest corner of the area (Figures 21 and 13 in back pocket), mostly south of the Vermilion River and west of the Landonville ridge. This unit forms a discontinuous thin cover which appears to be laterally equivalent to Diamicton Units D and E, and overlies Diamicton Unit C or on bedrock. Thickness varies between 1 and 8 metres.

4.3. REGIONAL CORRELATIONS

The first logical step to integrate Vermilion stratigraphy into a regional framework is to compare it with the stratigraphy of the Sand River map sheet (NTS 73L) located directly north of the Vermilion map sheet (NTS 73 E) and with the general stratigraphy developed for eastern Alberta and Saskatchewan.

Detailed stratigraphic investigations were performed by Fenton and Andriashek (Andriashek, 1985, Andriashek and Fenton, 1989) in the Sand River map sheet using lithological and mineralogical properties to characterize Quaternary formations. They identified four main glacial formations which include (from the oldest to the youngest) the Bronson, the Bonnyville, the Marie Creek and the Grand Center Formations as described in chapter one. Average values for the textural and mineralogical properties attached to these formations (Table 7) are numerically slightly different than those obtained in the Vermilion survey area. However the relative comparison of properties between units is very similar and a correlation of the stratigraphy in the two adjacent map areas is possible. The limitations of using physical properties alone as stratigraphic tools were already discussed in Chapter 2. The following is a comparison of the properties and characteristics of units in both map sheets according to their stratigraphic position (Tables 6 and 7).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Kenilworth Lake
Lloydminster
Battle River
41
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29

Figure 21: DISTRIBUTION OF DIAMICTON UNIT F

X Alberta Reseach Council boreholes and numbers

• Alberta Environment boreholes

○ Diamicton Unit F identified

4.3.1 STRATIFIED UNIT A

Drillers logs for the adjoining Sand River map sheet have identified sand and gravel resting on bedrock and in pre-glacial valleys. The Vermilion lowermost Stratified Unit A is probably equivalent to the lowest member of the Empress Formation which overlies Cretaceous bedrock, is present in the preglacial valleys bottoms and does not contain clasts of lithologies from the shield.

4.3.2 DIAMICTON UNIT A

Diamicton Unit A in the Vermilion area correlates with the Bronson Formation (Tables 6 and 7). Diamicton A and the Bronson Formation both rest either directly on bedrock or on stratified, sorted deposits in preglacial channels and both show very low resistivity on electric logs and have a high clay content. No coarse sand mineralogy is available from Unit A found in the Vermilion map area. The clayey texture of the Bronson Formation and of Diamicton Unit A is the result of eroding the underlying Lea Park Formation. This lowermost till was not identified in areas where the Belly River Formation underlies Quaternary sediment and as a result the lowermost clayey till overlying the Lea Park shale in deep preglacial valleys (Figures 9 and 10 in back pocket) is interpreted to be Bronson equivalent. It is possible that the texture of this diamicton unit becomes sandier when it overlies the friable sandstone of the Belly River Formation.

4.3.3 STRATIFIED UNIT B

Based on the stratigraphic position and the presence of granitic clasts in this sand and gravel which suggest a glaciofluvial origin, it is correlated with the Muriel Lake Formation.

4.3.4 DIAMICTON UNIT B

Diamicton Unit B in the Vermilion area is identified by its stratigraphic position and by its coarse sand mineralogy which is characterized by a relatively low amount of plutonic and metamorphic rocks, high quartz, and low carbonates. These properties correlate well with the Bonnyville Formation properties. The Bonnyville Formation was described by Andriashek as having two diamicton sub units separated in most places by a gravelly to sandy horizon. This stratified interval is present north of the North Saskatchewan River in Diamicton Unit B (Figure 10) but the differentiation of two subunits was not possible with the lower density of analytical data available for the Vermilion area. Both the Bonnyville Formation and Diamicton Unit B show strong oxidation at many locations.

4.3.5 STRATIFIED UNIT C

Stratified unit C was correlated with the Ethel Lake Formation on the basis of its stratigraphic position. The presence of granitic clasts again indicates a glacial origin but no mineralogical or textural properties are available to differentiate it from other gravel or sand related to the earlier of later glaciofluvial deposits.

4.3.6 DIAMICTON UNIT C

Diamicton Unit C, rich in carbonates with a lower quartz content and generally sandier matrix texture (Table 6) correlates well with the distinctively carbonate rich till called Marie Creek Formation (Table7) present in the Sand River area. Also, it occupies the same stratigraphic position that of the second youngest glacial formation.

4.3.7 STRATIFIED UNIT D

Stratified unit D was correlated with the Marie Creek Formation on the basis of its stratigraphic position. The presence of granitic clasts again suggests a glaciofluvial origin but no mineralogical or textural properties are available to differentiate it from other gravel or sand related to the earlier of later glaciofluvial deposits.

4.3.8 DIAMICTON UNIT D

Diamicton Unit D which outcrops over a large part of the Vermilion area is a clayey diamicton with a coarse sand fraction containinng a high content of plutonic and metamorphic grains and the lowest quartz and local rock content (Table 6). The hummocky moraine associated with this unit is the continuation of the uppermost till of the Grand Center Formation of the southeast part of the Sand River map Sheet. The coarse sand mineralogy of these two diamicton bodies is relatively similar: the Reita Lake and Hilda Lake members of the Grand Center Formation have the highest plutonic and metamorphic grains content, lowest quartz and local rock content of the diamicton units present in the Sand River survey area (Table 7). The texture of the Reita Lake member is sandier than the clayey Hilda Lake member: it is possible that the clayey Diamicton Unit D is a composite of the two members. The Hilda Lake and Reita Lake members are believed to have a northeastern origin as indicated by the southwest trending flutes. Flutes located in the Diamicton Unit D, southwest of Frog Lake show a similar trend.

4.3.9 DIAMICTON UNIT E

Diamicton Unit E is well defined geographically and stratigraphically and outcrops in a narrow band of terrain in the Northern Valley Lowlands It has a surface streamlined towards the southeast until it reaches the Vermilion River where the flutes fade into low relief ice disintegration and ice crevasse fillings. Diamicton Unit E has well defined properties such as sandy texture, a coarse sand mineralogy similar to Diamicton Unit D, (table 6) and distinct contact with underlying deposits. The Kehiwin member of the Grand Center Formation is geographically and stratigraphically adjacent to this unit and has similar properties: e.g.sandy texture, similar relative coarse sand mineralogy and sharp contact with underlying diamicton (Table 7). The Kehiwin member is also fluted, but in a more southerly direction. It is possible that Diamicton Unit E was reworked by the same ice body which deposited the Vilna member of the Grand Center Formation, as it has a more southeasternly trend than the flutes of the Kehiwin moraine.

4.3.10 DIAMICTON UNIT F

Diamicton Unit F is defined as a highly variable diamicton package, containing glacially displaced sediments including bedrock. Its lithological and textural characteristics exhibited a wide range . This is not surprising as this diamicton unit outcrops in areas of shallow bedrock, rubble or thrusted moraine where the stratigraphy is discontinuous and disturbed and where there is incorporation of older sediments. In a few boreholes, Diamicton Unit F was thick enough and its characteristics were consistent enough to attempt classification. In such instances, Diamicton Unit F properties are quite similar to the properties of Diamicton Unit D. Geographically, it should correlate with Vilna member of the Grand Center Formation. However, there is no evidence that the two are equivalent and therefore the Diamicton Unit F is not correlated with any definite formation.

CHAPTER FIVE DESCRIPTION AND INTERPRETATION OF FACIES

5.1 FACIES IN GLACIAL ENVIRONMENTS

The concepts of facies and facies modelling are not new and have been extensively used in marine and fluvial sedimentology and more recently in the glacial depositional environment (Lawson, 1979, 1981a, 1981b; Eyles, 1979; Eyles et al.,1988; Ashley, Shaw and Smith, 1985; Proudfoot, 1985; Dreimanis, 1985; Kulig, 1986; Shaw, 1987; Shaw and Ashley, 1988). The term facies is used here as defined by Middleton (1978) as being the "lithological, structural and organic aspects detectable in the field". The facies scheme used here was developed in the field and includes textural composition, primary sedimentary structures (e.g. bedding, lamination, grading, sorting), secondary structures (e.g. folds, faults, boudinage) and other features such as presences of dropstones, draped clasts, soft clasts, pebble coating. Munsell Color and weathering are included in the field description but are not used in facies description.

The objectives of this chapter are to describe facies observed during the inspection of sections through selected landforms of the Vermilion area (individual section descriptions in Appendix 4). These selected landforms are associated with glacial deposition and erosion, consist mostly of diamictons and are traditionally mapped as stagnant ice moraine, fluted moraine, rubble moraine and glaciotectonic terrain.

The facies classification used here (Tables 8 and 9) resembles classifications used by fluvial sedimentologists. An assemblage of letters represents a combination of characteristics of a facies. The first letter in the code is a capital letter and describes the dominant texture of the material (e.g. D for diamicton, S for sand). The next letter(s) describe(s) a minor textural component, primary sedimentary structure, or secondary structure as required to identify the facies (e.g. Ds indicates

Table 8 Facies Symbols and Descriptions

Fine-grained sediment	
Fw	well sorted silt and fine sand
Fwf	well sorted silt and fine sand, faulted/folded
Fwm	well sorted silt and fine sand, massive
Sand	
Sw	well sorted sand
Swm	well sorted sand, medium-grained
Spm	poorly sorted sand, medium-grained
Spf	poorly ssorted sand, faulted/folded
Su	unsorted sand
Sum	unsorted sand, massive
Suf	unsorted sand faulted/folded
Gravel	
Gw	well sorted gravel
Gp	poorly sorted gravel
Gum	unsorted gravel, massive
G-B	boulder lag
Diamicton	
Dm	massive diamicton
Ds	massive diamicton with sand lenses
Dss	massive diamicton with sand stringers
Dbs	banded diamicton and silty sand
Dsi	interbedded diamicton, silt and sand
Dk	massive diamicton and incorporated sediment
Bedrock	
B	bedrock
Bf	folded or faulted bedrock

Table 9 SUMMARY OF FACIES CHARACTERISTICS

SYMBOL	FACIES	DIAGNOSTIC PROPERTIES	INTERPRETATION
Dm	MASSIVE DIAMICTON	-unstructured appearance -pockets of diamicton with different texture -poorly defined bi-modal fabric -silt and clay coating on pebbles	melt out or supraglacial till
Ds	MASSIVE DIAMICTON WITH SAND LENSES	-unstructured appearance except or stratified lenses -lenses show cross-bedding, faulting , folding -random orientation of fabric	supraglacial or melt out till
Dss	LAYERED DIAMICTON WITH SAND STRINGERS	- bands of massive diamicton with thin, short sand stingers -sand stringers show smudging, streching and boudinage -occasional striated stones	lodgement till
Dbs	BANDED DIAMICTON AND SILTY SAND	-massive diamicton interspaced with thin,long sandy and silty lenses -lenses continuous over a few meters -lenses often have coarse fraction at bottom and concave down lower contact with diamicton -folds and convolutions common	subaerial gravity flow
Dsi	INTERBEDDED DIAMICTON, SAND AND SILT	-massive diamicton interbedded with continuous silt and fine sand laminae -mud clasts common	subaqueous gravity flow sediment
Dk	MASSIVE DIAMICTON WITH INCORPORATED BLOCKS OF SEDIMENT	-massive diamicton with large inclusions -inclusions consist of bedrock, sand or gravel	combination meltout and supraglacial till
Bf	DISTURBED BEDROCK	folded, faulted or displaced	glaciotectonically disturbed bedrock

a diamicton with sand lenses, Dsl a diamicton with sand laminae).

The term diamicton is used here as "any nonsorted or poorly sorted sediment that contains a wide range of particle size" (Dreimanis, 1982). The average textural range of diamicton in the map area is composed roughly of 35% clay, 30% silt, 35% sand in combination with coarser fragments which range from pebble to boulder size.

The term "massive" refers to the absence of any sedimentary structure. "Stratified" implies bedding, lamination or definite sorting of particles. "Banded" and "layered" refer to a visible tabular structure up to 1 centimeter thick which does not have well defined contacts between bands or layers and presents a very poorly sorted to unsorted appearance.

5.2 FACIES DESCRIPTIONS AND INTERPRETATIONS

5.2.1 Dm: MASSIVE DIAMICTON

This facies has a silty clay to sandy clayey silt matrix texture, with less than 5% coarse fragments of granules to cobble size with occasional boulders. The only sedimentary structures present are rare small sand lenses (<2 cm.) and occasional pockets of diamicton with a slightly different texture with poorly defined boundaries (Plate 9). No imbricated or striated clasts were observed. Soft clasts were found in one exposure and silt and clay coatings on pebbles are present at most sites. Contact with in-situ bedrock was observed in one section and does not show banding, shearing or abrasion marks.

Upper and lower contacts with other facies are gradational and are usually detectable within a thin contact zone. Fabric measurements collectively show a poorly defined bi-modal orientation (Figure.22). Thickness ranges from 1 to 10 metres or more, and lateral extension can be greater than 14 metres.
Example: this facies is found in sections CM86-5, CM86-8, CM86-11 (see Appendix 4).

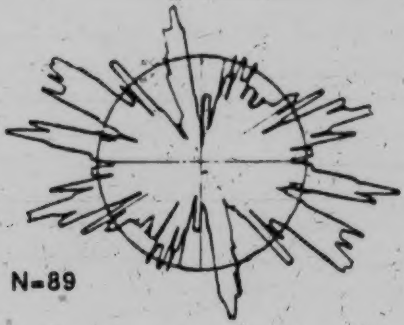


Figure 22 Fabric of Oriented Clasts, Massive Diamicton Facies (Dm)

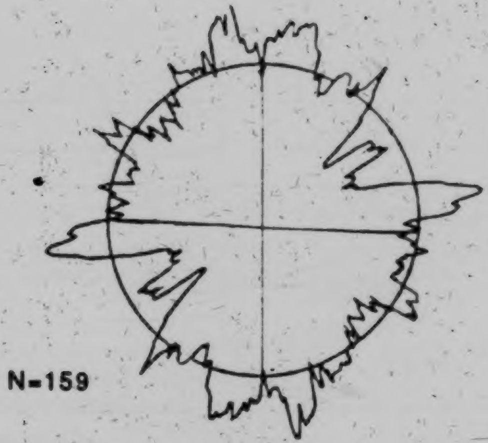


Figure 23 Fabric of Oriented Clasts, Massive Diamicton with sand lenses Facies (Ds)

INTERPRETATION

The lack of internal organization, grading or sorting and the presence of diffuse, discontinuous bodies of diamicton with different textures , features characteristic of Dm were described as properties of melt out till (Boulton, 1976; Dreimanis, 1987; Elson, 1961; Lawson 1976, 1979; Shaw 1982; Haldorsen and Shaw, 1982).

Slow gradual melting upwards of debris rich englacial and basal ice releases sediment with minimum influence of sorting processes. Fine particles occupy the space between larger particles, resulting in a massive, unsorted deposit that shows little to no grading. Clasts are also deposited without much reworking such that the preferred orientation associated with ice transport is preserved. Slight variation of the ice debris content may cause variation in the diamicton matrix texture. Other facies characteristics which may indicate melt out process are its tabular nature (Lawson 1979), its association with stagnant ice terrain (Dreimanis, 1987) and thin clay and silt coating on pebbles and clasts (Elson, 1961). Characteristics described in literature as indicative of melt-out till not observed in Dm are bands of cohesive material that appear to drape clasts, a statistically preferred orientation of pebbles (Lawson 1976), augen and truncated structures preserved by sublimation (Shaw 1977). Fabric measurements in Dm do not show strong orientation which may be due to rapid melting occurring from above and below resulting in a remobilization of deposits and loss of a well defined fabric if such a fabric previously existed.

This facies could also be formed when earlier glacial sediments are redeposited as the supporting ice walls or floor melt. As the ice melts, saturated sediment fails, slides and accumulates and all previous sedimentary structures of the slumped deposits are destroyed (Lawson, 1979). In such cases, the fabric would not be expected to show consistent unimodal or bimodal fabric, but a polymodal or random orientation. This depositional mechanism is therefore possible in some of the locations were fabric measurement were not performed or were observed as random.

It is important to include facies associations as part of the overall depositional model and this seems to apply particularly to the massive diamicton facies where the lack of diagnostic features observable in the field do not always permit a final interpretation. This facies was therefore considered in conjunction with other associated facies in Chapter 6.

5.2.2 Ds: MASSIVE DIAMICTON WITH SAND LENSES

This facies has similar physical characteristics as Massive Diamicton (Dm) and contains lenticular bodies of well sorted sand and gravelly sand which may be massive or trough cross-stratified. These lenses range from 0.2 to 1.5 metres in thickness and from 0.2 to 2.5 metres in length (Plate 10). Small scale secondary structures such as folding and faulting are also present. Blocks of diamicton cutting into the stratified sand beds were observed in a few sand bodies, deforming the underlying sand beds. Lower contact of the lenses with the diamicton is usually well defined, sub-horizontal to convex. Upper contact with the diamicton can be well defined to mixed. Fabric measurement in this facies showed a random orientation (Figure 23).

Upper contacts of Ds are usually poorly defined and gradational. Thickness ranges from 1 to 5 metres and is found laterally for distances up to 6 metres.

Example: This facies is found in sections CM82-257 and CM82-99 (see Appendix 4).

INTERPRETATION

The unstructured nature of the diamicton and the presence of stratified sorted sands in Ds suggest the coexistence of processes that will release unsorted massive sediments and stratified sands. This can be accomplished by cavities at the base of the glacier which act as channels for melt water. This channeled water deposits stratified sorted sediment such as sand and gravel (Boulton, 1970, 1972; Haldorsen and Shaw, 1982; Lawson, 1979; Shaw, 1979; Shaw and Kvill; 1984, Shaw, Kvill and Rains, 1989). The stratified bodies are then preserved in the surrounding massive diamicton as the melt out process take place. The lenses of sand and gravel do not show evidence of shearing or mixing if the ice was static, or folding and faulting if they were deposited on stable sediments (Dreimanis, 1987). Minor faults and deformation may occur during melting of the underlying ice as settling of the deposit continues.

The coexistence of diamicton and well sorted sand inclusions as described in Dms is also possible when saturated supraglacial debris accumulates in low areas or depressions in melting ice. The glaciers covering the Prairies probably had an upper ice zone with fairly low debris concentration and the melting of such an upper clean ice would expose a debris rich ice zone and release an ample supply of meltwater. As relief develops on the melting surface, debris slumps and accumulates in the form of massive to poorly sorted diamicton, meltwater is channeled and deposits poorly to well sorted stratified sand and gravel (Lawson 1979). These stratified sediments may be preserved if they are deposited on fairly stable base or if only minor disruption occurs as the underlying ice melts.

Both environments could generate faults and/or fractures if deposited on an unstable base such as ice cored deposits. Both environments may explain the presence of blocks of diamicton cutting into the stratified sand beds. However the presence of faulting and folding and the random fabric orientation described in Ds indicate an environment with an unstable base such as that caused by collapse due to underlying melting ice. Thus this facies is usually interpreted as a supraglacial melt out when strong deformation features were present in the stratified lenses (Proudfoot, 1985).

5.2.3 Dss: LAYERED DIAMICTON WITH SAND STRINGERS

This facies exhibits discontinuous bands of diamicton interfingering with thin, discontinuous, lenticular bands of moderately well sorted massive sands (Plate 11).

The diamicton bands have a clay silt matrix texture with minor amount of pebbles. These bands are discontinuous over a few metres and are subparallel to the topography. Their thickness is irregular and varies between 2 to 10 centimetres. The contact between diamicton bands are fissility planes subparallel to the topography. The diamicton often appears mottled and iron-stained with a well developed fissility or strong platiness present within individual diamicton bands.

The interspaced sand stringers consist of very fine-grained to medium-grained, moderately well to well sorted, massive sands. They are found in elongated, stringy bodies and seem to have been stretched, smudged or squeezed. Their thickness varies between 0.5 cm and 3 cm and their length between 10 to 45 cm. Boudinage and mixing at the contact with the diamicton are common and very common at the ends of the sand bodies. Striated stones are present in two sections. No dropstones, imbricated stones, draped stones or soft clasts were observed.

Lower or upper contacts were not observed. The thickness of this facies varies between 0.5 to 2 metres and lateral extent is as great or greater than 10 metres.

Example: This facies is found in sections CM86-1, CM86-6 and CM86-13 (see Appendix 4).

INTERPRETATION

Features such as smudged or smeared inclusions, (Kruger, 1979, Dreimanis, 1987), layers of well sorted sediments due to dewatering (Muller, 1983), presence of layers, lenses or blocks of water sorted sediment showing interdigitation with till, striated clasts, faulting and shearing (Shaw, 1973, 1976), fluted surface (Boulton, 1976b) and distinct fissility reflecting unloading of ice (Boulton, 1976, from Dowdeswell and Sharp, 1986) are all properties of lodgement till. The sand stringers of Dss show definite shearing and are interpreted to be the result of lodgement processes during the subglacial deposition of this facies.

5.2.4 Dbs: BANDED DIAMICTON AND SILTY SAND

This facies consists of diamicton bands with irregularly spaced, thin, fine-grained sand and silt lenses (Plates 12a and 12b). The diamicton bands have a clayey to silty matrix texture with traces of coarse fragments of pebble size which are sometimes concentrated at the base of the bands. The diamicton bands are continuous over a few metres and of consistent thickness (1 to 6 cm) with tapered ends.

The laminae are composed of moderately well sorted silty sand to fine-grained sand with a very minor amount of medium-grained sand. They are continuous over 0.5 to 2 metres, are fairly thin (0.5 to 2 cm) and are irregularly spaced within the diamicton bands. Undisturbed laminae are usually subparallel to each other and have slightly concave lower contacts with the underlying diamicton. Contacts between diamicton bands and the sandy bodies consist of interfingering tapered ends. Secondary features such as faulting and folding were observed in many exposures. In some exposures, others secondary structures such as large convolutions and folds were present. Most lower contacts are well defined and conformable. Striated pebbles were present in two exposures of this facies. No draped stones or dropstones were observed. Orientation of the bands or laminae plunge between 5 degree dip to 45 degree dip but are subparallel within a particular facies measured within a section.

Lower and lateral contacts with other facies are usually well defined. Facies thickness varies between 0.1 to 3.0 metres and lateral extent varied between 0.4 to 4.1 metres.

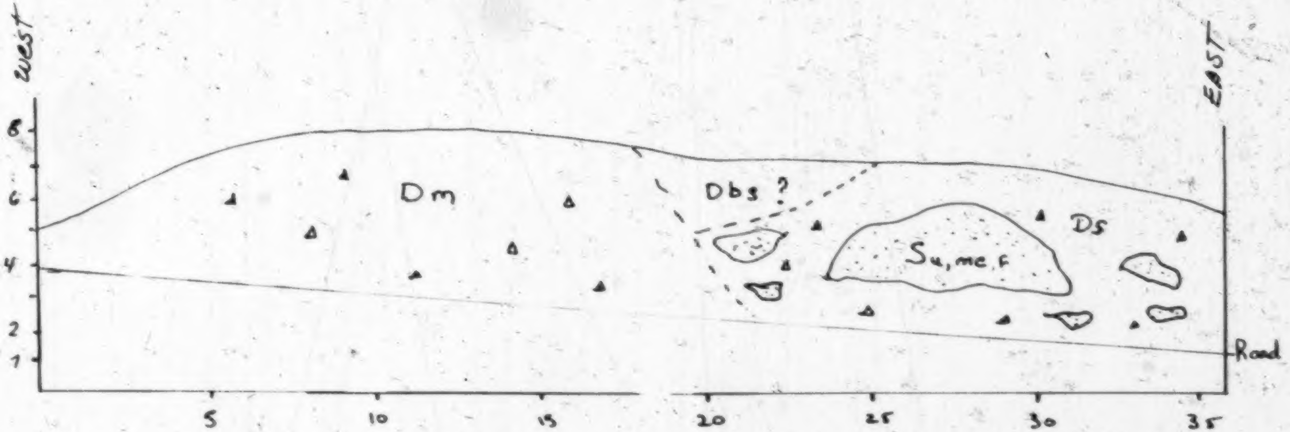
Example: This facies is found in sections CM83-103, CM86-8 and CM86-11 (see Appendix 4).

INTERPRETATION

The discontinuous and lenticular nature of the diamicton bands and sand laminae observed in Dbs suggest deposition in a rapidly changing environment (Eyles, 1979; Lawson, 1979 and 1981; Haldorsen and Shaw, 1982) such as multiple sediment gravity flow events. The unsorted, massive nature of the diamicton and the absence of well sorted bedded continuous bodies or soft clasts suggest a subaerial and not a subaquous deposition of the material (Lawson, 1982).

According to Lawson's (1982) observations, sediment gravity flow can account for up to 75% of the total volume material deposited at the ice margin. He describes sediment flow as a continuum of deposits types which range from low water content with a discrete plug and shear zones (where the sediment strength acts as the grain support mechanism) to a high water content flow which may be fully liquefied. These diamicton layers are often overlaid by a thin layer of massive silt deposited by meltwater flowing onto the surface of the lobe surface. Plug deposits are poorly sorted to unsorted material which may include contorted layered of these silt caps and older flow sediment. As water content increases, the shear zone increases in thickness until the flow is in shear throughout the thickness of the lobe (Lawson, 1981). Coarse particles at the base may be deposited as a gravel zone of tractional origin develops. Liquefaction occurs with even greater water content which results in the deposition of well sorted thin and lenticular silty sand layers. Contacts between individual flows are usually conformable and non-erosional except for the more liquid and channelized types. As flow is initiated and fed by meltwater, the water content within a flow will change along its trajectory and multiple flows are also very common in such a saturated environment of melting stagnant ice.

Multiple flow deposition results in a stratified deposit of interlayered meltwater and sediment flow material or layers of interfingering discontinuous diamicton bands, with discontinuous bodies of silts. Such features are present in


west
EAST
8
6
4
2
1
Dm
Dbs ?
Su, me.f
Ds
Road
5
10
15
20
25
30
35

CM 86-2 **STAGNANT ICE MORAINE**

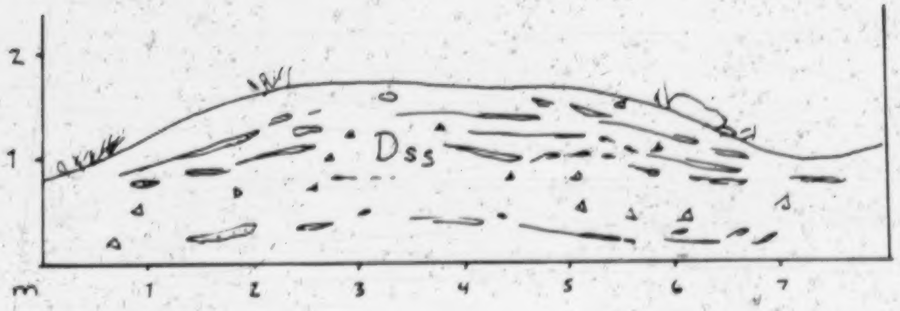
LOCATION: UTM N: 81, UTM E: 43

Dm: massive diamicton

Dk: massive diamicton with sand lenses

Dbs: banded diamicton and silty sand

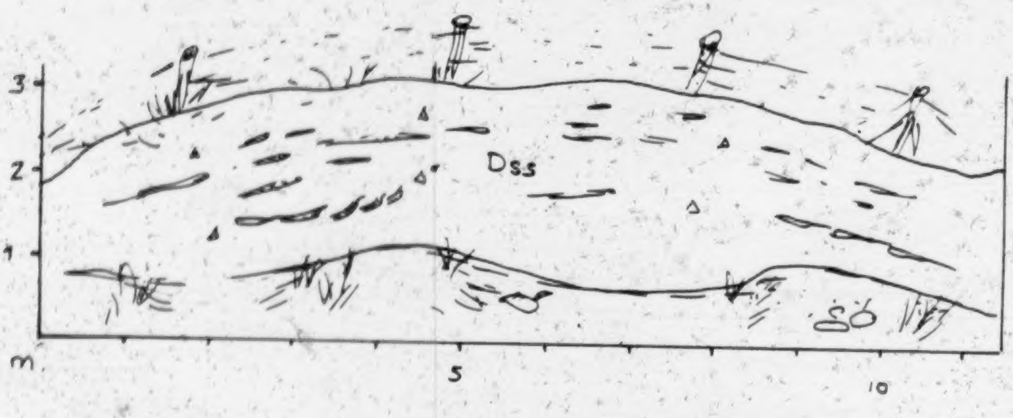
Suf: sand, m-c gr., unsorted,faulted(poorly stratified)


2
1
Dss
m
1
2
3
4
5
6
7

CM86-1 **FLUTED MORAINE**

LOCATION: TWP 54, RGE 4 W 4, SEC. 11, LSD NE 16

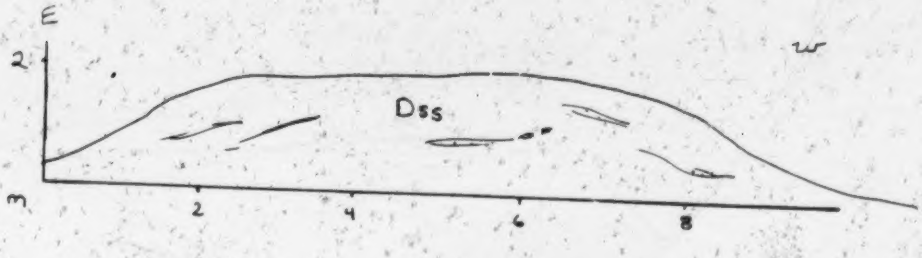
Dss: diamicton with sand stringers


3
2
1
m
5
10
Dss

CM86-6 **FLUTED MORAINE**

LOCATION: TWP 55, RGE 4 W 4, SEC. 5, LSD sw 13

Dss: diamicton with sand stringers

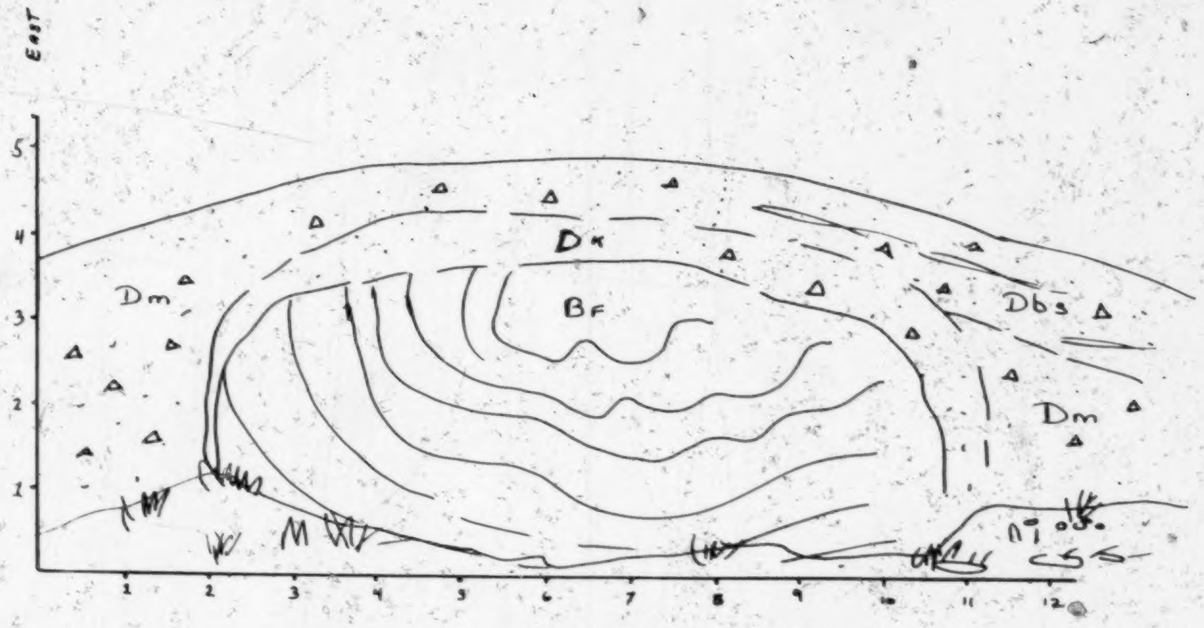


RG-314 **FLUTED MORAINE**

LOCATION: TWP 57, RGE 7 W 4, SEC. 34, LSD 13

Dss: diamicton with sand stringers

Dss presented well developed platiness subparalle to the topography.


EAST
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
Dm
Dk
Bf
Dbs
Dm

CM82-51 **RUBBLE MORAINE**

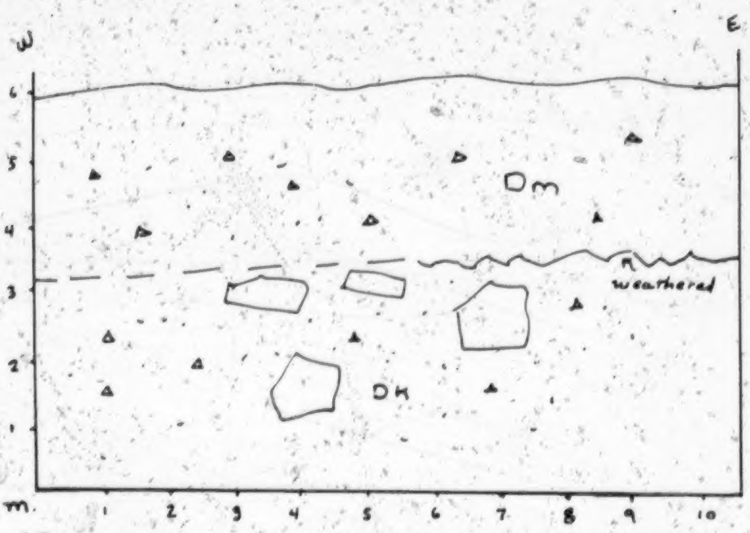
LOCATION UTM: N: 41 UTM E: 81

Dm: massive diamicton

Dk: massive diamicton with inclusions

Dbs: banded diamicton and sand

Bf: disturbed bedrock

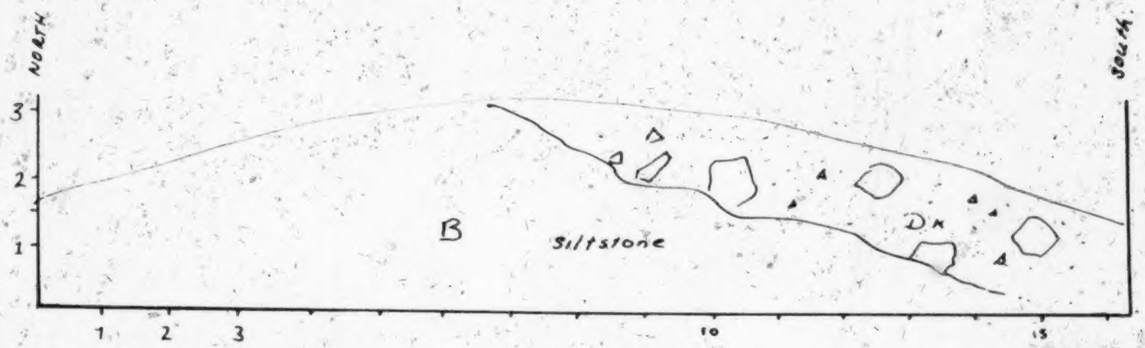

W
E
6
5
4
3
2
1
m.
1
2
3
4
5
6
7
8
9
10
Dm
weathered
Dk

CM82-70 **RUBBLE MORAINE**

LOCATION: TWP 54, RGE 6 W 4, SEC. 8, LSD NW 5.

Dm: massive diamicton (unweathered)

Dk: massive diamicton with inclusions (weathered)

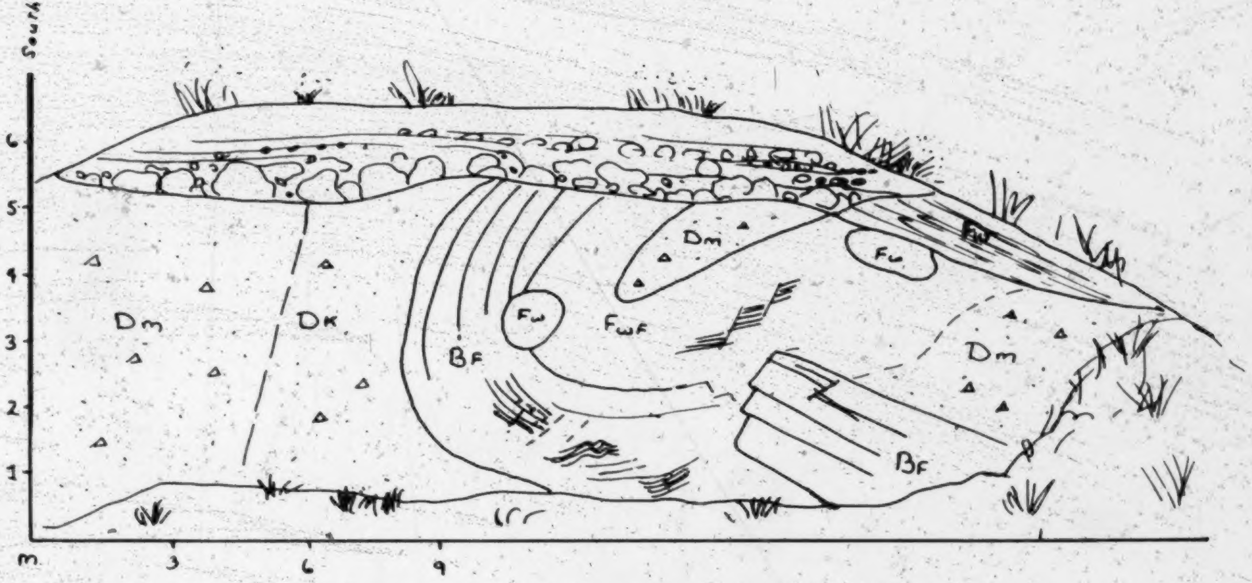

NORTH
SOUTH
3
2
1
B
Siltstone
Dk
1
2
3
10
15

CM82-76 **RUBBLE MORAINE**

LOCATION: TWP 54, RGE 6 W 4, SEC 22, LSD SW 12.

Dk: massive diamicton with inclusions

B: undisturbed bedrock


South
6
5
4
3
2
1
m.
3
6
9
Dm
Dk
Bf
Fw
Fwf
Dm
Fw
Fw
Dm
Bf

CM84-2 **RUBBLE MORAINE**

LOCATION: TWP 48, RGE 2 W 4, SEC. 8, LSD NW 12.

Dm: massive diamicton

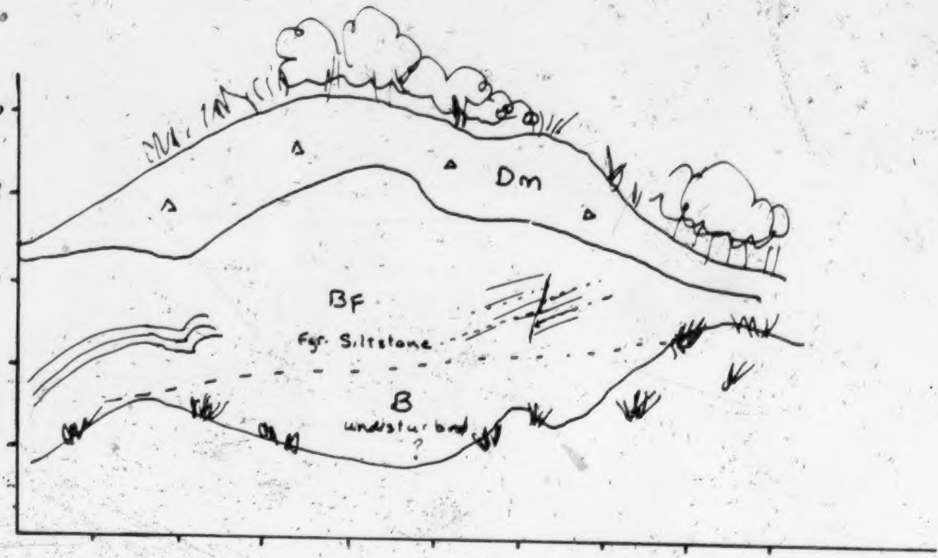
Dk: massive diamicton with inclusions

Bf: disturbed bedrock

Fwf: silt and fine sand , well sorted, faulted

Fw: silt and fine sand , well sorted

Gp: poorly sorted gravel, unstratified


10
8
6
4
2
Dm
Bf
Fgr. Siltstone
B
undisturbed
?

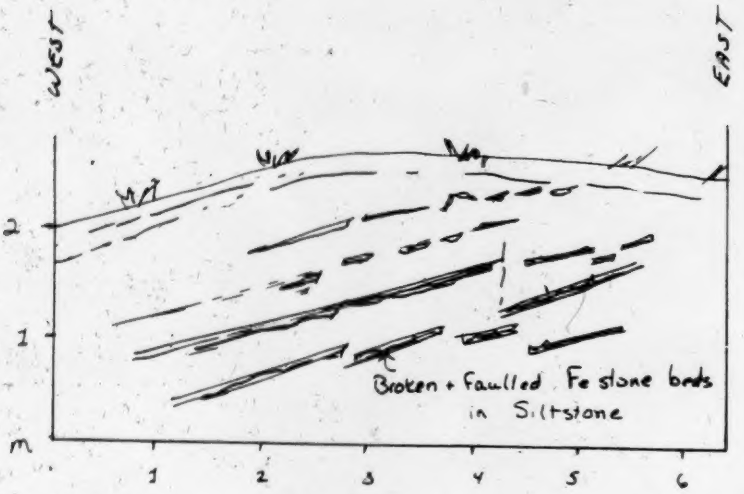
CM82-65 **THRUSTED MORAINE**

LOCATION: TWP 53, RGE 6 W 4, SEC. 11, LSD NE 15

Dm: massive diamicton

Bf: disturbed bedrock, silstone,

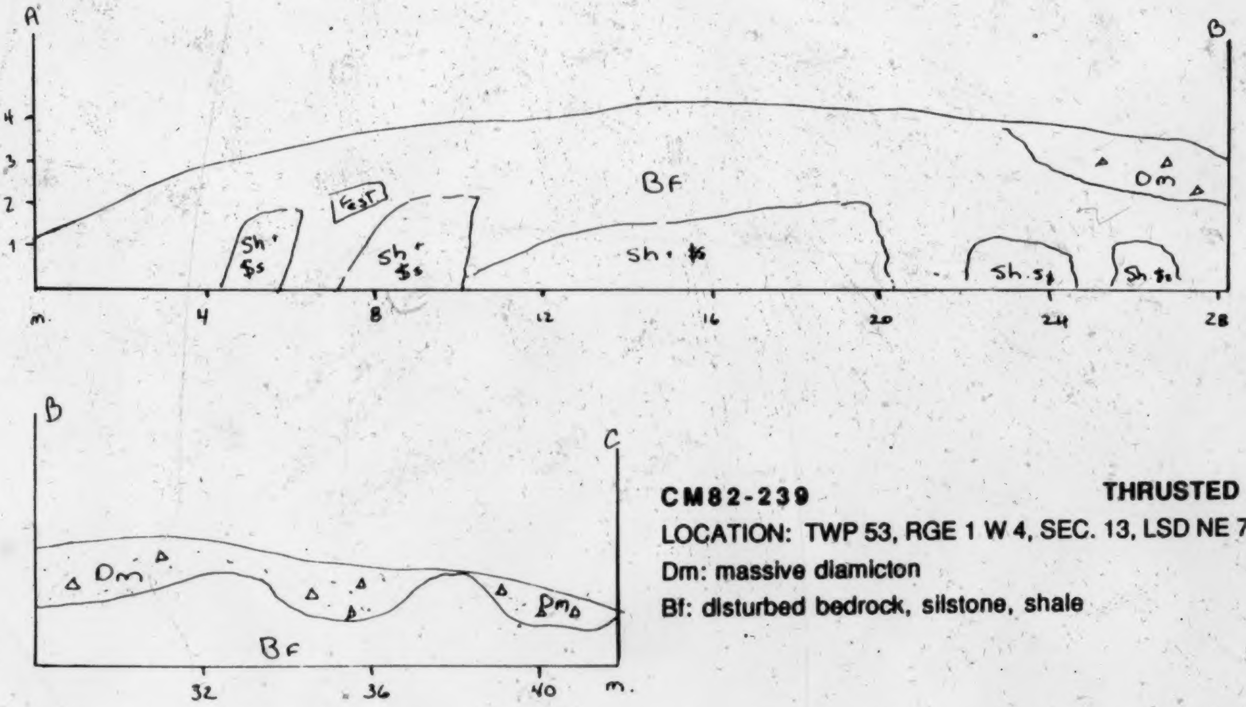
B: undisturbed bedrock, silstone


WEST
EAST
2
1
m
1
2
3
4
5
6
Broken + faulted Fe stone beds in Siltstone

CM82-213 **THRUSTED MORAINE**

LOCATION: TWP 53, RGE 3 W 4, SEC. 16, LSD NW 12

Bf: disturbed bedrock, silstone, shale

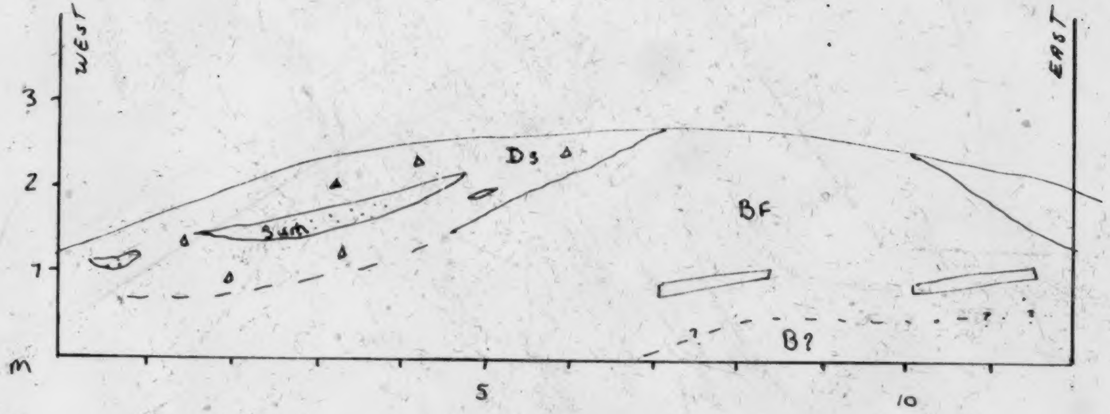

A
B
C
4
3
2
1
m.
4
8
12
16
20
24
28
32
36
40
m.
Bf
Dm
Sh.
Sh. Ss
Sh. St
Est
Dm
Bf

CM82-239 **THRUSTED MORAINE**

LOCATION: TWP 53, RGE 1 W 4, SEC. 13, LSD NE 7

Dm: massive diamicton

Bf: disturbed bedrock, silstone, shale

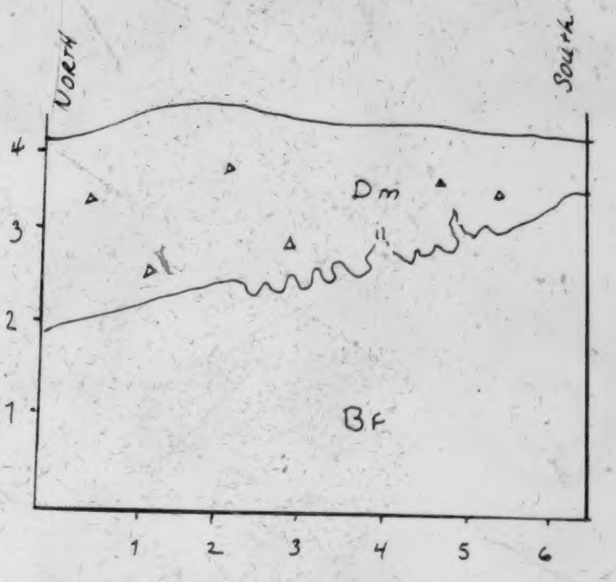

WEST
EAST
3
2
1
m
5
10
Ds
Sum
BF
B?

CM82-240 **THRUSTED MORAINE**

LOCATION: TWP 53, RGE 1 W 4, SEC. 13, LSD NE 5.

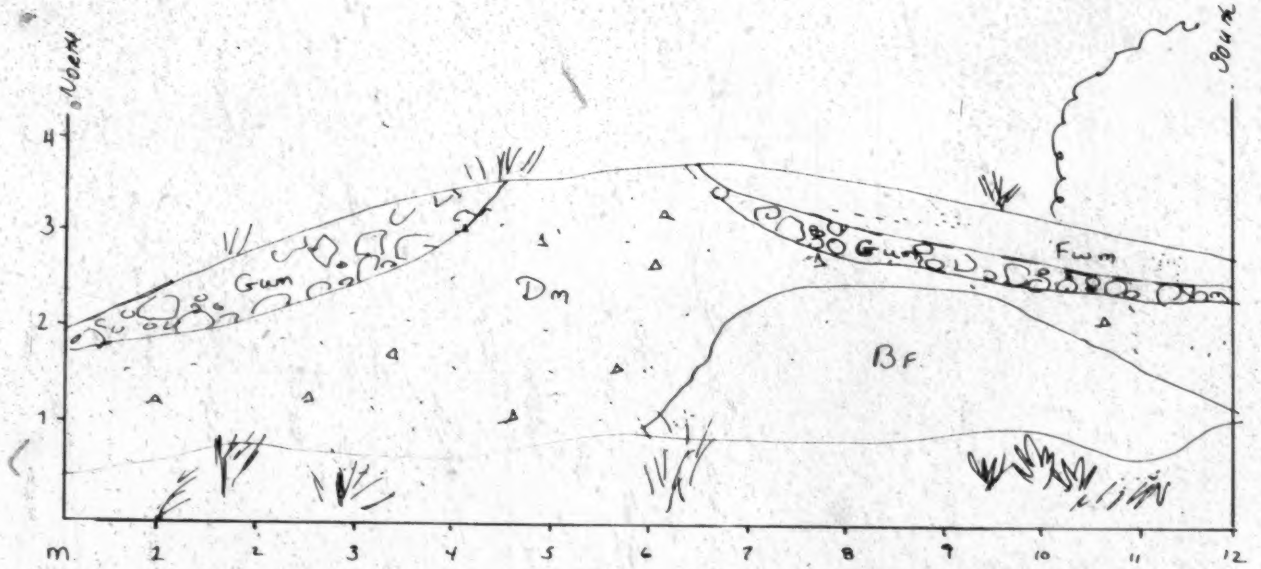
CM84-6 **THRUSTED MORAINE**

LOCATION: TWP 54, RGE 6 W 4, SEC. 1, LSD SE 1


NORTH
SOUTH
4
3
2
1
Dm
Bf
1
2
3
4
5
6

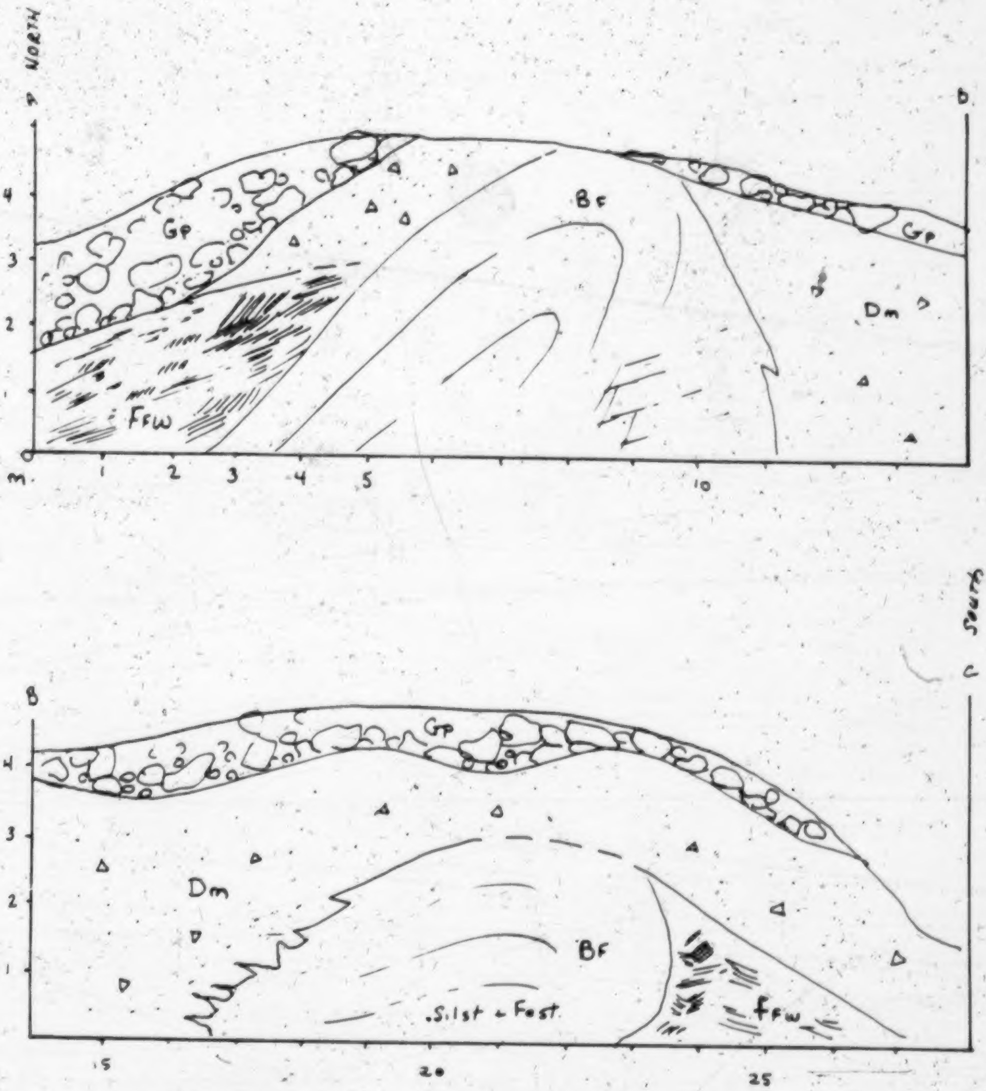
Dm: massive diamicton

Bf: disturbed bedrock, silstone and shale


North
South
4
3
2
1
m
1
2
3
4
5
6
7
8
9
10
11
12
Gum
Dm
Gum
Fwm
Bf

CM84-9 **THRUSTED MORAINE**

Fwm: fine-gr. sd and silt, well sorted , massive
Gum: gravel, unsorted, massive
Dm: massive diamicton
Bf: disturbed bedrock, silstone



NORTH
B
Gp
Bf
Dm
Gp
Ffw
4
3
2
1
m
1
2
3
4
5
10
SOUTH
B
C
Gp
Dm
Bf
Silst + Fsst
Ffw
4
3
2
1
15
20
25

CM86-17 **THRUSTED MORAINE**

LOCATION TWP 47, RGE 1, SEC 14, LSD SW 16

Dm: massive diamicton

Bf: disturbed bedrock

Ff: fine sand and silt, faulted

Gp: poorly sorted gravel, unstratified

VERMILION EAST - QUATERNARY STRATIGRAPHY
CROSS SECTION D - D'

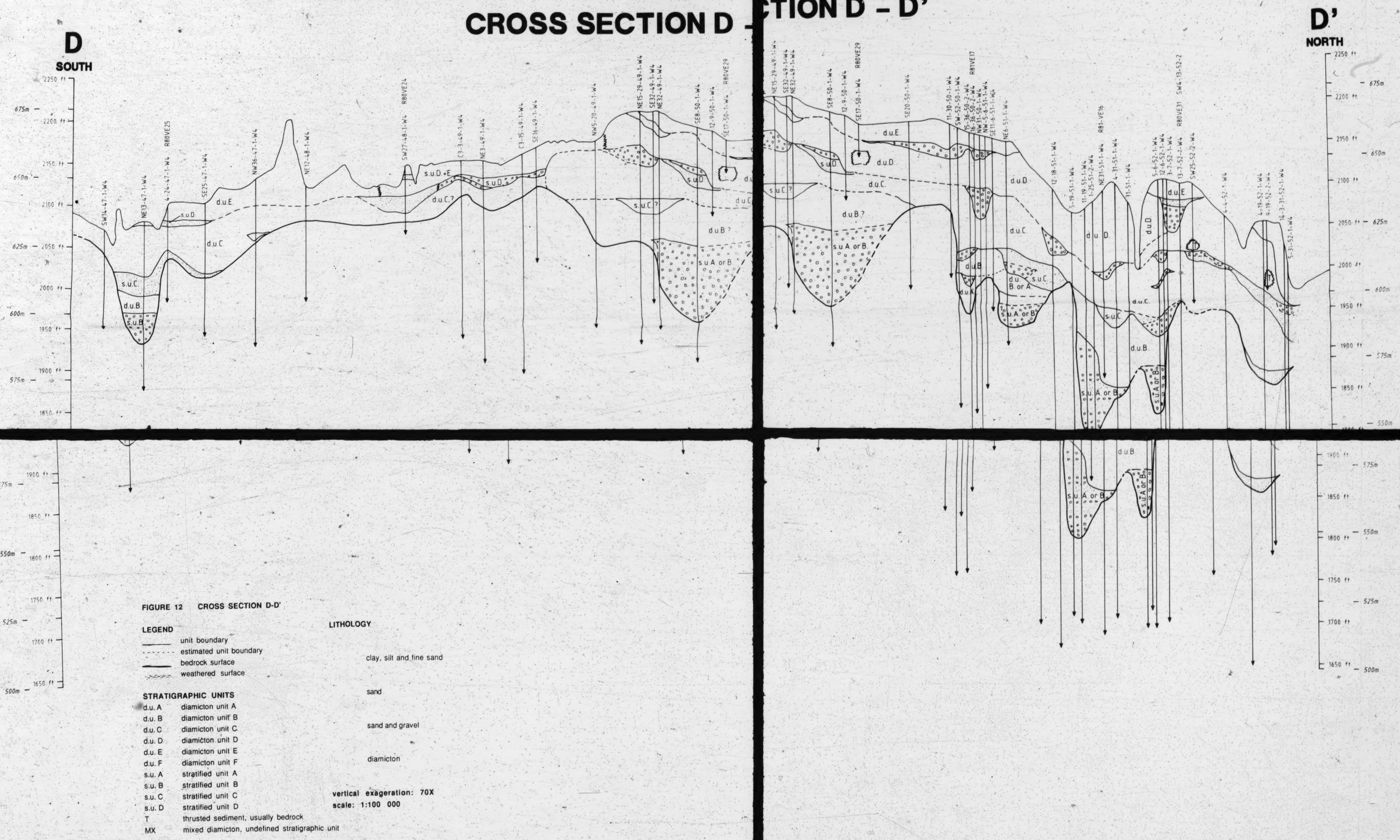

D
SOUTH
D'
NORTH
2250 ft
2200 ft
2150 ft
2100 ft
2050 ft
2000 ft
1950 ft
1900 ft
1850 ft
1800 ft
1750 ft
1700 ft
1650 ft
675m
650m
625m
600m
575m
550m
525m
500m
s.u.C
d.u.B
s.u.B
s.u.D
d.u.E
d.u.C
s.u.D+E
s.u.D
d.u.C?
s.u.C?
d.u.B?
s.u.A or B
d.u.D
d.u.E
d.u.B
d.u. B or A
s.u.C
s.u.A or B
d.u.B
s.u.C
d.u.D
s.u.A or B

FIGURE 12 CROSS SECTION D-D'

LEGEND

- unit boundary
- estimated unit boundary
- bedrock surface
- weathered surface

STRATIGRAPHIC UNITS

d.u. A	diamicton unit A
d.u. B	diamicton unit B
d.u. C	diamicton unit C
d.u. D	diamicton unit D
d.u. E	diamicton unit E
d.u. F	diamicton unit F
s.u. A	stratified unit A
s.u. B	stratified unit B
s.u. C	stratified unit C
s.u. D	stratified unit D
T	thrusted sediment, usually bedrock
MX	mixed diamicton, undefined stratigraphic unit

LITHOLOGY

clay, silt and fine sand

sand

sand and gravel

diamicton

vertical exageration: 70X
scale: 1:100 000

Figure 12

VERMILION EAST - QUATERNARY STRATIGRAPHY
CROSS SECTION E - E'

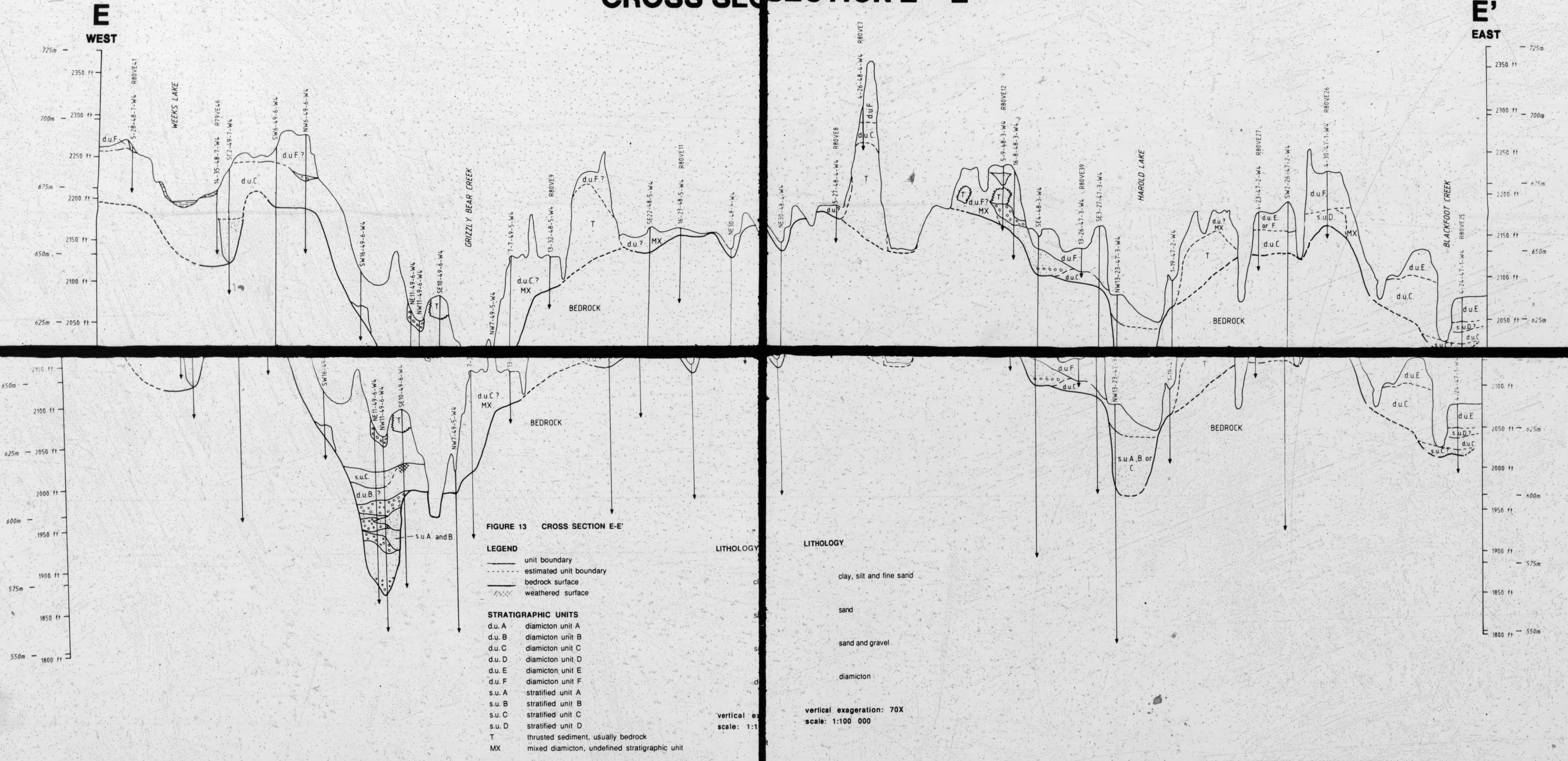

E
WEST
E'
EAST
725m
700m
675m
650m
625m
600m
575m
550m
2350 ft
2300 ft
2250 ft
2200 ft
2150 ft
2100 ft
2050 ft
2000 ft
1950 ft
1900 ft
1850 ft
1800 ft
WEEKS LAKE
GRIZZLY BEAR CREEK
HAROLD LAKE
BLACKFOOT CREEK
R80VE41
5-28-48-7-W4
R79VE46
14-35-48-7-W4
SE2-49-7-W4
SW6-49-6-W4
NW6-49-6-W4
SW16-49-6-W4
NE11-49-6-W4
NW11-49-6-W4
SE10-49-6-W4
NW7-49-5-W4
7-7-49-5-W4
R80VE9
13-32-48-5-W4
SE22-48-5-W4
R80VE11
16-21-48-5-W4
NE30-48-4-W4
R80VE8
5-27-48-4-W4
R80VE7
4-26-48-4-W4
R80VE12
5-9-48-3-W4
16-8-48-3-W4
SE4-48-3-W4
R80VE39
13-26-47-3-W4
SE3-27-47-3-W4
NW13-23-47-3-W4
1-19-47-2-W4
R80VE27
4-23-47-2-W4
SW2-26-47-2-W4
R80VE26
4-30-47-1-W4
R80VE25
4-24-47-1-W4
d.u.F
d.u.F ?
d.u.C
d.u.C ?
d.u.E
d.u.E or F
d.u.?
d.u.B ?
s.u.C
s.u.D
s.u.D ?
s.u.C ?
s.u.A and B
s.u.A, B or C
T
MX
BEDROCK

FIGURE 13 CROSS SECTION E-E'

LEGEND

unit boundary
estimated unit boundary
bedrock surface
weathered surface

STRATIGRAPHIC UNITS

d.u. A	diamicton unit A
d.u. B	diamicton unit B
d.u. C	diamicton unit C
d.u. D	diamicton unit D
d.u. E	diamicton unit E
d.u. F	diamicton unit F
s.u. A	stratified unit A
s.u. B	stratified unit B
s.u. C	stratified unit C
s.u. D	stratified unit D
T	thrusted sediment, usually bedrock
MX	mixed diamicton, undefined stratigraphic unit

LITHOLOGY

clay, silt and fine sand

sand

sand and gravel

diamicton

vertical exageration: 70X
scale: 1:100 000

Figure 13

VERMILION EAST - QUATERNARY STRATIGRAPHY
CROSS SECTION C - C'

C
SOUTH
C'
NORTH
2350 ft
2300 ft
2250 ft
2200 ft
2150 ft
2100 ft
2050 ft
2000 ft
1950 ft
1900 ft
1850 ft
1800 ft
1750 ft
1700 ft
1650 ft
700m
675m
650m
625m
600m
575m
550m
GRIZZLY BEAR CREEK
VERMILION PARK LAKE (VERMILION RIVER VALLEY)
LANDONVILLE RIDGE
d.u.F?
d.u.F
d.u.E
d.u.D
d.u.D?
d.u.C
d.u.B
d.u.B?
d.u.B or C
s.u.C
s.u.C or B
s.u.A or B
MX
T
T?

FIGURE11 CROSS SECTION C-C'

LEGEND

unit boundary
estimated unit boundary
bedrock surface
weathered surface

STRATIGRAPHIC UNITS

d.u. A	diamicton unit A
d.u. B	diamicton unit B
d.u. C	diamicton unit C
d.u. D	diamicton unit D
d.u. E	diamicton unit E
d.u. F	diamicton unit F
s.u. A	stratified unit A
s.u. B	stratified unit B
s.u. C	stratified unit C
s.u. D	stratified unit D
T	thrusted sediment, usually bedrock
MX	mixed diamicton, undefined stratigraphic unit

LITHOLOGY

clay, silt and fine sand
sand
sand and gravel
diamicton

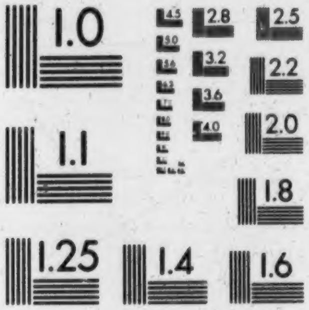
vertical exageration: 70X
scale: 1:100 000

104
75
E10
1:40,000
17-5-50
AS132
5312
43

1820
5012
105
73
E10
53° 42
1:40,00
49-1
PAN
A5182
5

4 of/de 4

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



1.0
4.5
5.0
5.6
6.3
7.1
8.0
9.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

PRECISION℠ RESOLUTION TARGETS

SURFICIAL GEOLOGY OF THE VERMILION-EAST AREA
EAST-CENTRAL ALBERTA
1:250,000 scale

LEGEND EXPLANATION

MAP UNIT NOTATION

The map notation system allows the map user to obtain rapidly the general lithology, morphology and relief of a polygon as well as a general genetic class, a polygon being the area defined by the delineations on the map. Not all symbols are present in all map units due to insufficient data. Map units are usually representative of the upper 3 metres and the symbol respresents at least 75% of the map unit compostion. When two morainic map units are present in the polygon, a complex genetic code is used.

The first letter or prefix (when present) is a lower case letter and indicates the textural composition of the map unit as evaluated in the field. In morainic units, the composition symbol is absent as they are usually composed of diamicton. The term diamicton is used in its broader meaning and consists of a unstructured, unsorted to very poorly sorted mixture of clay, silt, fine to coarse sand, pebbles, cobbles and boulders. Texture symbols describing two categories such as *sg* for sand and gravel may referto unsorted sand and gravel or interbedded sand and gravel.

The second letter is an upper case letter and indicates genesis. Seven major genetic categories were identified and are represented by a capital letter. An second or third letter is usually added to the code to include a secondary genesis (e.g. *MF* = fluted moraine, *FG*= glaciofluvial).

The last portion of the code or suffix describes t the continuity of a deposit (e.g. *d*=discontinuous), the morphology of the surface (e.g. *h*=hummocky), or the thickness of a unit (e.g. *v*=veneer), the amount of relief of a unit (e.g. *1* = less than 3 metres relief).

EXAMPLES:

gFGm1 - glaciofluvial gravel with a low rolling relief

bLGSv veneer of glaciolacustrine silt and sand over
_____fh1 stagnant ice moraine with the entire unit having a
MSU flat to low hummockytopography

The last portion of the code or suffix describes t the continuity of a deposit (e.g. *d*=discontinuous), the morphology of the surface (e.g. *h*=hummocky), or the thickness of a unit (e.g. *v*=veneer), the amount of relief of a unit (e.g. *1* = less than 3 metres relief).

EXAMPLES:

gFGm1 glaciofluvial gravel with a low rolling relief

bLGSv veneer of glaciolacustrine silt and sand over
_____fh1 stagnant ice moraine with the entire unit having a
MSU flat to low hummockytopography

COMPOSITION

a: SAND, SILT AND CLAY
b: SAND AND SILT
c: CLAY
b: FINE-GRAINED;SILT AND CLAY
g: GRAVEL AND SAND
s: SAND
t: DIAMICTON
r: BEDROCK, UNDIVIDED

GENETIC CLASS

O: ORGANIC
C: COLLUVIUM RECENT
F: FLUVIAL
E: EOLIAN
L: LACUSTRINE
G: GLACIAL
B: BEDROCK

GENETIC MODIFIER

E: ERODED
S: SLUMPED
D: DISSECTED
E: ERODED
F: FLUTED
G: GLACIAL
IC: ICE CONTACT
T: TRANSVERSE
R: RUBBLE
S: STAGNANT ICE
SC: CREVASSE FILLING
SD: DOUGHNUT MOUND
SI: IRREGULAR STAGNANT ICE
T: THRUST

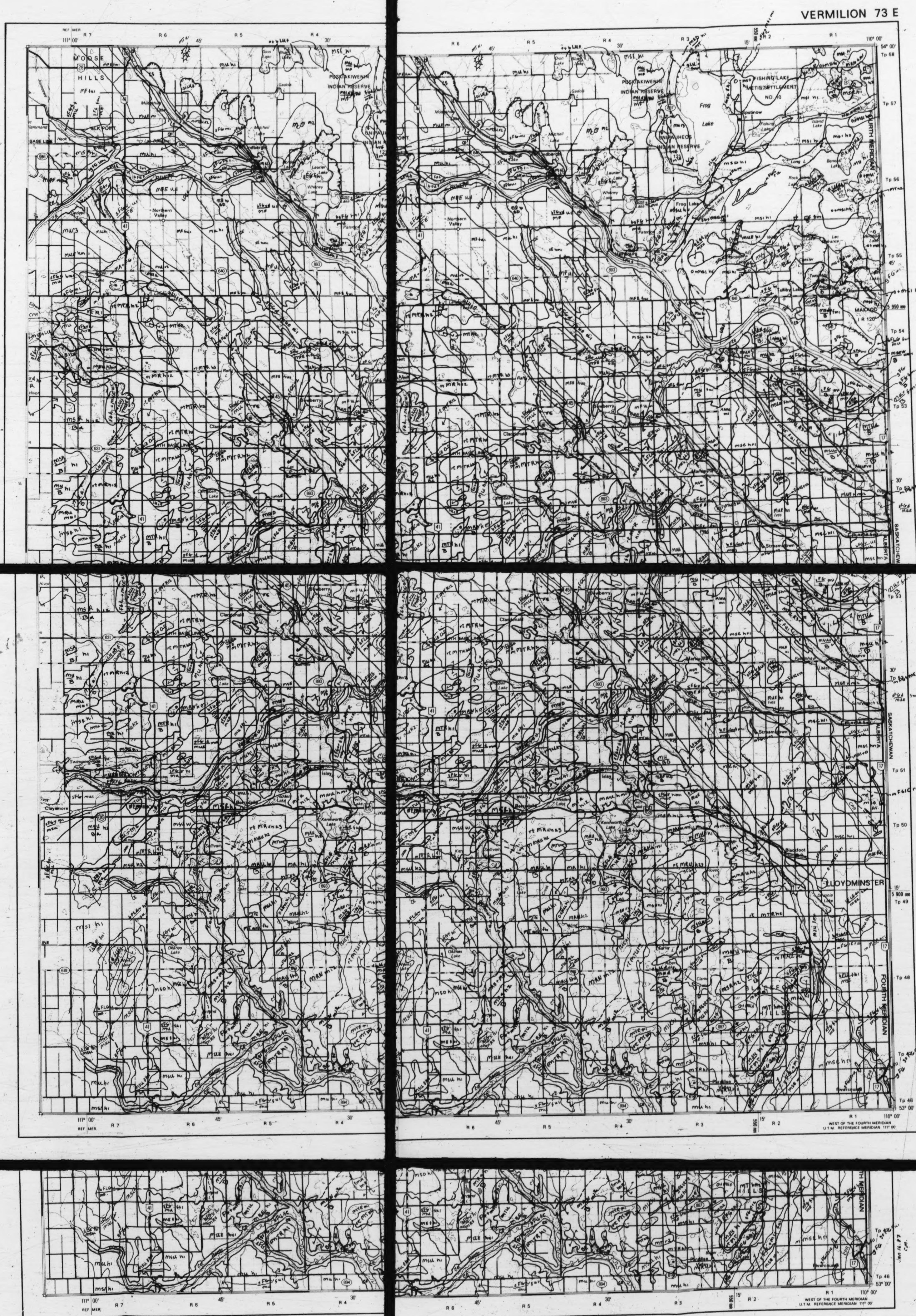
MORPHOLOGY AND RELIEF

d: DISCONTINUOUS
b: DRAPED
f: FLAT
h: HUMMOCKY
k: KNOBS
m: ROLLING
r: RIDGES
t: TERRACE
u: UNDULATING
b: VENEER
1: LOW LOCAL RELIEF (<3 METERS)
2: MEDIUM LOCAL RELIEF (3 TO 10 METERS)
3: HIGH LOCAL RELIEF (>10 METERS)

Mapped by C. Mougeot , 1983-1985

h: HUMMOCKY
k: KNOBS
m: ROLLING
r: RIDGES
t: TERRACE
u: UNDULATING
b: VENEER
1: LOW LOCAL RELIEF (<3 METERS)
2: MEDIUM LOCAL RELIEF (3 TO 10 METERS)
3: HIGH LOCAL RELIEF (>10 METERS)

Mapped by C. Mougeot , 1983-1985



Alberta
TRANSPORTATION

SCALE 1 : 250 000

km 5 0 5 10 15 20 km
miles 5 0 5 10 15 miles

PRODUCED BY THE SURVEYS AND MAPPING BRANCH,
ALBERTA TRANSPORTATION, EDMONTON. © COPYRIGHT 1980

15 20 km
10 15 miles
BRANCH,
PYRIGHT 1980

VERMILION EAST - QUATERNARY STRATIGRAPHY
CROSS SECTION B - B'

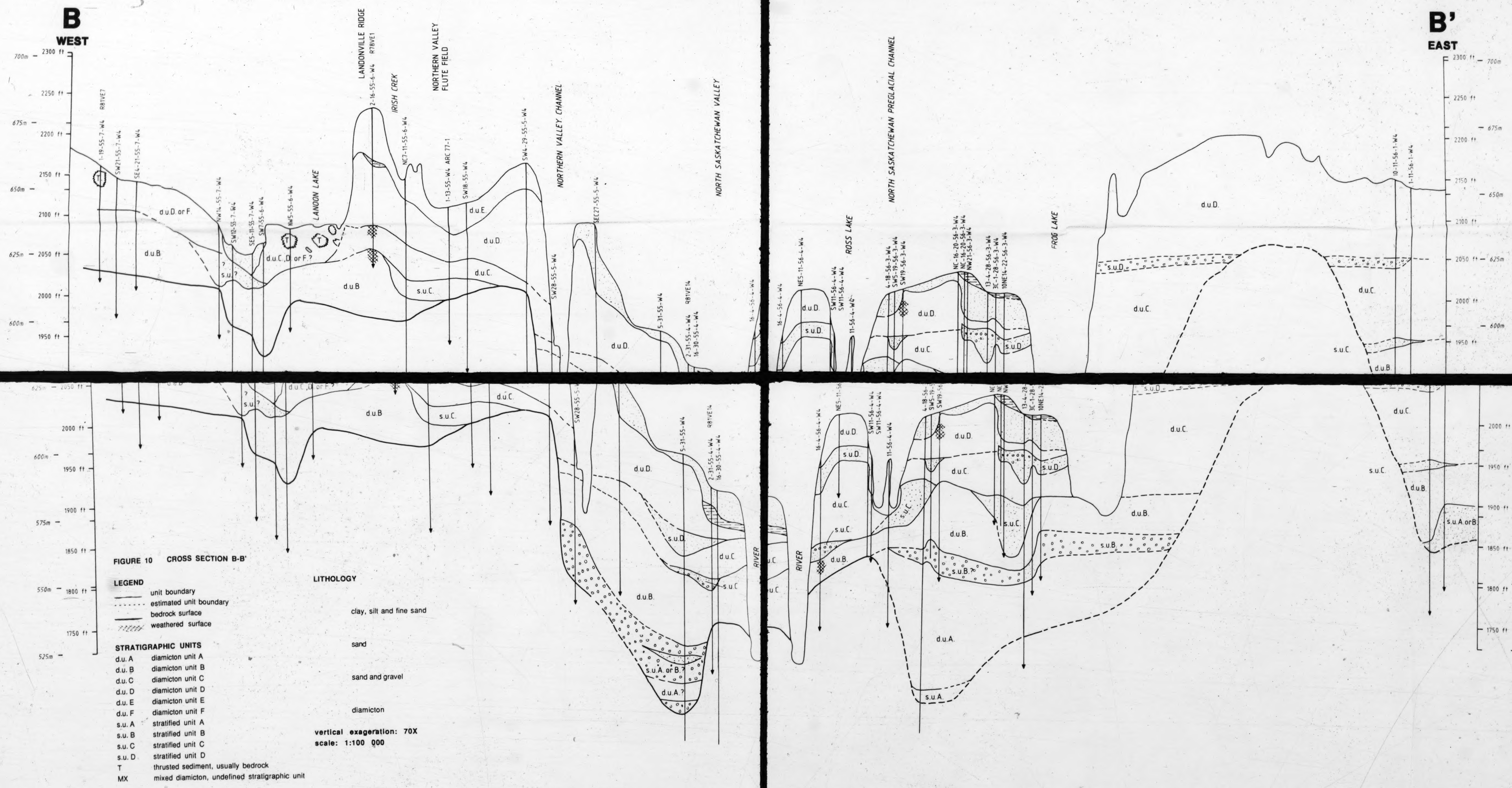

B
WEST
B'
EAST
2300 ft
2250 ft
2200 ft
2150 ft
2100 ft
2050 ft
2000 ft
1950 ft
1900 ft
1850 ft
1800 ft
1750 ft
700m
675m
650m
625m
600m
575m
550m
525m
LANDONVILLE RIDGE
IRISH CREEK
NORTHERN VALLEY FLUTE FIELD
NORTHERN VALLEY CHANNEL
NORTH SASKATCHEWAN VALLEY
ROSS LAKE
NORTH SASKATCHEWAN PREGLACIAL CHANNEL
FROG LAKE
LANDON LAKE
RIVER
R81VE7
1-19-55-7-W4
SW21-55-7-W4
SE4-21-55-7-W4
NW14-55-7-W4
SW12-55-7-W4
SE5-11-55-7-W4
SW7-55-6-W4
NW5-55-6-W4
2-16-55-6-W4
R78VE1
NC7-11-55-6-W4
1-13-55-W4
ARC 77-1
SW18-55-W4
SW4-29-55-5-W4
SW28-55-5-W4
SEC27-55-5-W4
5-31-55-W4
R81VE14
2-31-55-4-W4
16-30-55-4-W4
16-4-56-4-W4
NE5-11-56-4-W4
SW11-56-4-W4
11-56-4-W4
4-18-56-3-W4
SW5-19-56-3-W4
SW19-56-3-W4
NC-16-20-56-3-W4
NW21-56-3-W4
13-4-28-56-3-W4
3C-1-28-56-3-W4
10NE14-22-56-3-W4
10-11-56-1-W4
1-11-56-1-W4
T
d.u.D. or F.
d.u.B
s.u.?
d.u.C.,D. or F.?
d.u.E.
d.u.D.
d.u.C.
s.u.C.
s.u.D.
d.u.B.
s.u.B.?
s.u.B
s.u.A. or B.?
d.u.A.?
d.u.A.
s.u.A.
s.u.A. or B.

FIGURE 10 CROSS SECTION B-B'

LEGEND

unit boundary
estimated unit boundary
bedrock surface
weathered surface

STRATIGRAPHIC UNITS

d.u. A	diamicton unit A
d.u. B	diamicton unit B
d.u. C	diamicton unit C
d.u. D	diamicton unit D
d.u. E	diamicton unit E
d.u. F	diamicton unit F
s.u. A	stratified unit A
s.u. B	stratified unit B
s.u. C	stratified unit C
s.u. D	stratified unit D
T	thrusted sediment, usually bedrock
MX	mixed diamicton, undefined stratigraphic unit

LITHOLOGY

clay, silt and fine sand
sand
sand and gravel
diamicton

vertical exageration: 70X
scale: 1:100 000

Figure 10

VERMILION EAST - QUATERNARY STRATIGRAPHY
CROSS SECTION A - A'

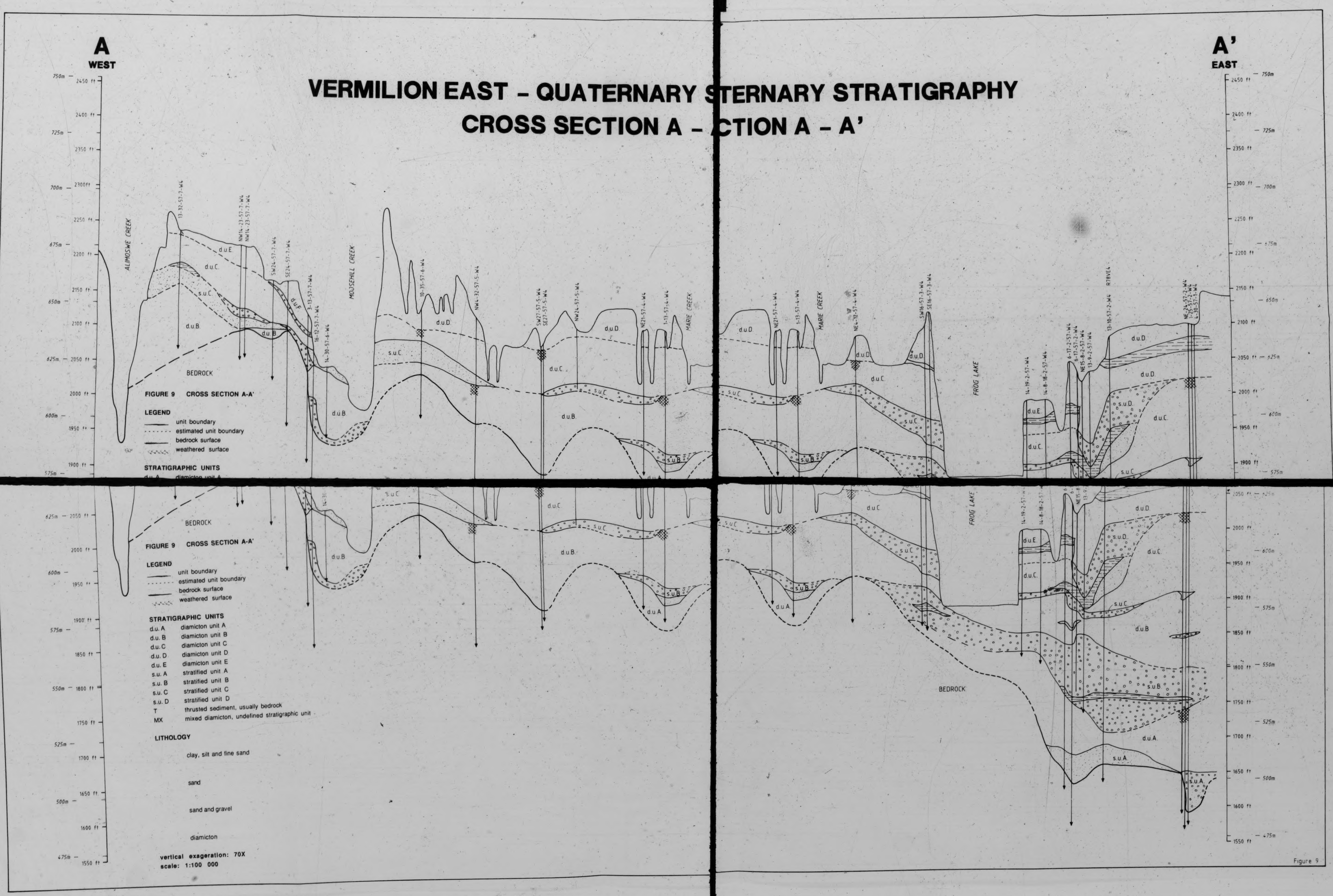

A
WEST
A'
EAST
750m
725m
700m
675m
650m
625m
600m
575m
550m
525m
500m
475m
2450 ft
2400 ft
2350 ft
2300 ft
2250 ft
2200 ft
2150 ft
2100 ft
2050 ft
2000 ft
1950 ft
1900 ft
1850 ft
1800 ft
1750 ft
1700 ft
1650 ft
1600 ft
1550 ft
ALIMOSWE CREEK
MOOSEHILL CREEK
MARIE CREEK
FROG LAKE
13-32-57-7-W4
NW14-23-57-7-W4
SW24-57-7-W4
SE24-57-7-W4
3-13-57-7-W4
16-12-57-7-W4
14-30-57-6-W4
10-35-57-6-W4
NW4-32-57-5-W4
SW27-57-5-W4
SE27-57-5-W4
NW24-57-5-W4
NE21-57-4-W4
1-13-57-4-W4
NE4-32-57-4-W4
SW16-57-3-W4
SE16-57-3-W4
14-19-2-57-W4
14-8-18-2-57-W4
6-17-2-57-W4
NE15-8-2-57-W4
13-9-2-57-W4
13-10-57-2-W4
R78VE4
NE-24-57-2-W4
1-30-57-1-W4
d.u.E
d.u.C
d.u.B
d.u.D
d.u.A
s.u.A
s.u.B
s.u.C
s.u.D
d.u.F
BEDROCK
Figure 9

FIGURE 9 CROSS SECTION A-A'

LEGEND

unit boundary
estimated unit boundary
bedrock surface
weathered surface

STRATIGRAPHIC UNITS

d.u. A	diamicton unit A
d.u. B	diamicton unit B
d.u. C	diamicton unit C
d.u. D	diamicton unit D
d.u. E	diamicton unit E
s.u. A	stratified unit A
s.u. B	stratified unit B
s.u. C	stratified unit C
s.u. D	stratified unit D
T	thrusted sediment, usually bedrock
MX	mixed diamicton, undefined stratigraphic unit

LITHOLOGY

clay, silt and fine sand
sand
sand and gravel
diamicton

vertical exageration: 70X
scale: 1:100 000